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ENGINEERING ANALYSIS OF LANDSAT 1 DATA FOR SOUTHEAST ASIAN AGRICULTURE

Final Report

NASA Contract NAS5-21844

ERTS Data Application Project U-160

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Engineering Analysis of Landsat 1 Data
For Southeast Asian Agriculture
U-160
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ABSTRACT

Data for five LANDSAT overflights became available on one test zone with less coverage on other zones. These were in the Gapan region: 31 October 1972, near the end of the wet season harvest but with some rice still standing; 18 November, during period of site preparation; 23 December, dry season (irrigated) rice in early stage of growth; 28 January 1973, dry season (irrigated) rice in middle stages of growth; and 21 June, during site preparation for the wet season. Thus it has not been possible to study a complete growing cycle, much less one full year of two (wet and dry season) crop cycles. Tests in the Gapan and Angat region are insufficient to draw generalities for growth cycles and spectral/temporal reflectance. However, spot confirmation from Nueva Ecija, Penaranda, and Bulacan test sites indicate that the rice sites cycle observed and used is similar to those in other regions except for a time phasing of the cycle.

Recognition of large (greater than a square kilometer) homogeneous rice areas can be achieved from LANDSAT color composites for multiple dates employing either manual or machine-aided analyses. However, the analysis is tedious by manual methods especially where multi-date imagery for the same locations must be identified. Unfortunately such large areas rarely occur in tropical agriculture. Small (such as one hectare or approximately one image pixel) heterogeneous rice areas occur regularly. Recognition of such areas and analysis of detailed rice growth status (vigor, plant variety, effectiveness of fertilization and irrigation, etc.), because of the complexities of the scene, requires use of LANDSAT digital data. This, in turn, requires a high-speed man-machine interactive analysis system to achieve efficiency and timely results in an operational system which examines large rice-growing areas. A General Electric IMAGE-100 machine was used on this project.

Use of two spectral bands of digital data (MSS 5 and MSS 6) appears to be adequate for site recognition and gross site status. Lowland rice sites can be readily detected from LANDSAT data if more than one (preferably several) overflights are used. LANDSAT spatial resolution was found to be satisfactory under these conditions. Signatures were extracted using a radiometric resolution of 64 levels in each spectral band. A finer resolution level (128) may be necessary for detailed assesment of rice status at a particular location. Both levels are beyond the capability of a manual visual system. The proper level must be selected with care to be meaningful.

The need for accurate position location (geometry) arises particularly in the signature extraction process for small training areas which must contain homogeneous rice and site conditions. Spectral/spatial/temporal signatures were found to be more powerful than spectral/spatial signatures alone. They are virtually essential for analyses of rice growth and sites in an environment where there is vegetation at most locations nearly all months of the year. Analysis of data incorporating temporal signature patterns, as a kind of fourth dimension feature, with other signature patterns is particularly difficult, with any speed, by human methods. Man-machine analysis becomes essential.

ENGINEERING ANALYSIS OF LANDSAT 1 DATA

FOR SOUTHEAST ASIAN AGRICULTURE

I. INTRODUCTION

Agriculture, in Southeast Asia, for the major part, consists of rice growing activities. For hundreds of millions of people in the tropical areas of the world, rice is the major staple food. Unfortunately, estimates of the areas devoted to rice growth or the yield of these areas are not reliable, either in terms of national or even of smaller regional areas. Only in very small local areas is reliable information obtained about the rice crop. Yield prediction often is too late for effective governmental planning and decisions. Since the late 1960's, when dreams of an ERTS/LANDSAT-type satellite as proposed by NASA, could be seen to be more than just imagination, it has seemed probable that ERTS-type imagery should be able to provide information of extreme value to tropical agriculture.

This project has focused upon the most important agricultural crop in the tropics. Rice, as grown in the tropics, does not happen to be the easiest crop to work with from an ERTS-type sensor. However, this project has demonstrated that an ERTS, now called LANDSAT 1, satellite can provide necessary information concerning not only rice growing but also concerning other natural resources expecially as to land use, crops, water and soil. When additional imagery becomes available from Landsat only a relatively short time, such as one crop season of data, would be necessary to verify and calibrate relationships discovered in this present project. An operational program could then be set up which would provide data as desired above for regional and national planning purposes.

For several decades Cornell University has had cooperative projects on agricultural subjects with agencies, institutions and personnel in the Philippines. A study of Southeast Asian agriculture, as conducted in the Philippines, especially with regard to rice-growing areas, should be applicable to most other rice-growing areas of Southeast Asia. This ERTS/LANDSAT research project has been worked out in cooperation with personnel at the University of the Philippines Agricultural College, Los Banos (UPLB) and with the International Rice Research Institute (IRRI) headquartered in Manila. Teams headed by Professor Senen Miranda of UPLB and by Dr. Thomas Wickham of IRRI respectively, have provided the ground truth data for this project. This has been a contribution of essential and expensive information by organizations in the Philippines at no cost to this project.

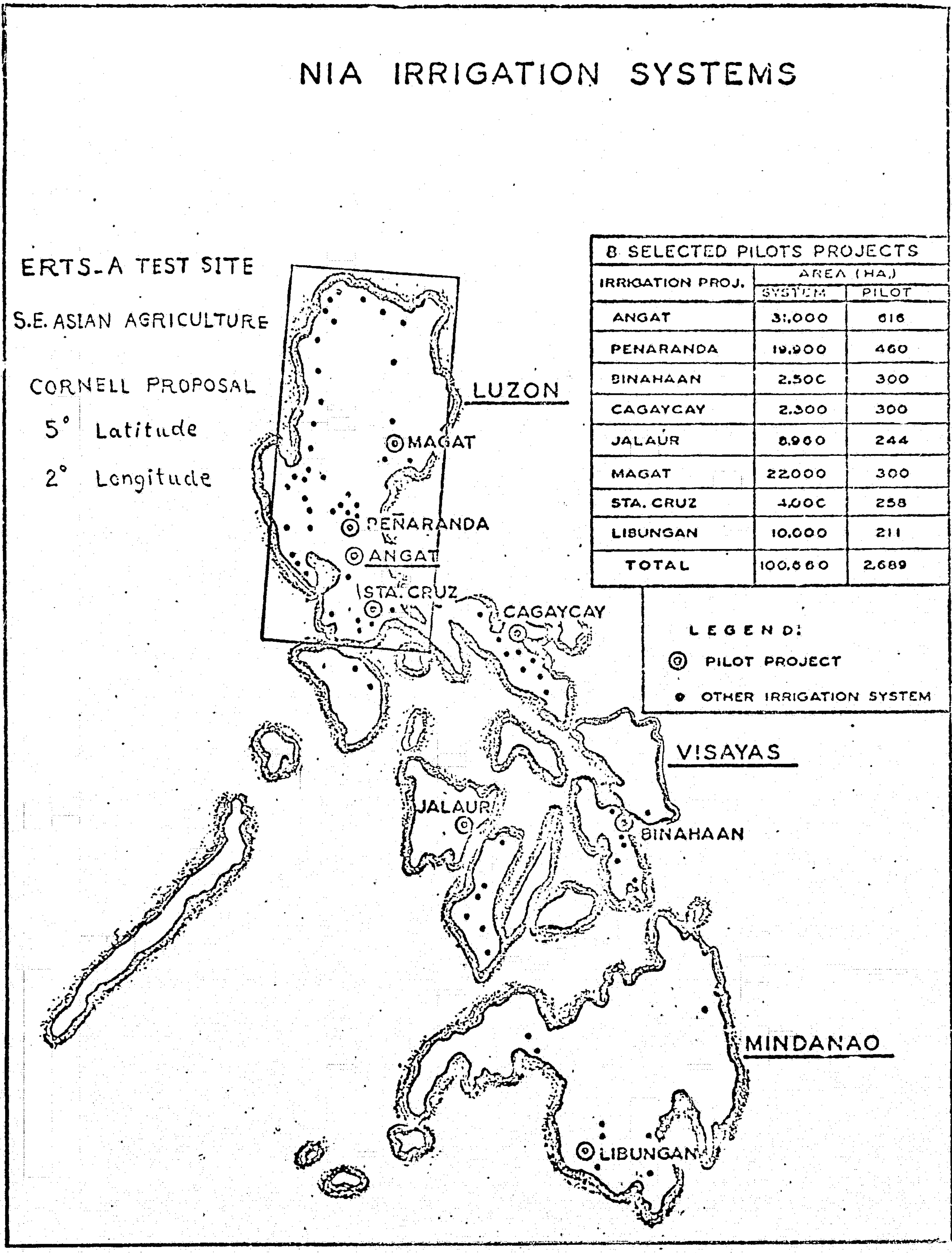
General Electric Company, Valley Forge Space Center, Pennsylvania, holds a sub-contract through Mr. Howard L. Heydt, Consulting Engineer in Earth Observatory Programs* The General Electric portion of the project has provided machine and machine-man interpretation of the LANDSAT

*Now Manager of G.E. Image-100 operations at Beltsville, MD.

I imagery. It has also provided the spectral, temporal and some of the spatial signature-acquisition data necessary for crop analyses.

Cornell University, Ithaca, New York directs the project and has investigated the man interpretation items. Professor Ta Liang is a co-investigator from the Cornell School of Civil and Environmental Engineering in the area of photo interpretation. Professor Gilbert Levine, from Cornell College of Agriculture and Life Sciences, is a co-investigator whose services are a financial contribution by the College to this NASA project. He provides liaison with the Philippine teams particularly in the soil, water and crop production area. Graduate research assistants for this project have been Billy J. Tucker from Fresno, California and Milegua F. Layese of UPLB, Philippines. Professor Arthur J. McNair from Cornell School of Civil and Environmental Engineering, has been the principal investigator, coordinating the project activities and working with the research assistants and co-investigators on interpretation items and basic spatial data.

The contract area on the island of Luzon, Philippine Islands is shown in Fig. 1. The contract reported upon herein has been supported by the National Aeronautics and Space Administration Under Contract NAS5-21844 with Cornell University and identified as ERTS Data Application Project U-160.



IRRIGATION PROJ.	AREA (HA.)	
	SYSTEM	PILOT
ANGAT	31,000	616
PENARANDA	19,900	460
BINAHAAN	2,500	300
CAGAYCAY	2,300	300
JALAUR	8,960	244
MAGAT	22000	300
STA. CRUZ	4,000	258
LIBUNGAN	10,000	211
TOTAL	100,660	2,689

Figure 1. The Philippines showing test sites

II. OBJECTIVES

This project has focused primarily on the rice cycles of land preparation, planting, growing, and harvest as interpreted through the analysis of ERTS/LANDSAT data. Efforts have been exerted to obtain as much information as possible (I) by human or manual methods and (II) by machine and automation methods, thereby enabling decisions to be made as to an economic mix of methods taking into consideration volume, speed, accuracy, cost, and efficiency under various conditions.

The questions encountered fall broadly into three areas:

A) How does rice in a known test area display itself to a Landsat sensor at various stages of land preparation, planting, growth and harvest?

B) What other, unknown, areas covered by a Landsat image reveal similar spectral characteristics or signatures at one stage or another and might be misidentified as rice?

C) What temporal changes in rice signatures during growth are displayed to a Landsat sensor which can be interpreted to reveal the location, welfare, and possible yield of a crop?

The principal objectives of this project thus become:

1) To establish the feasibility of extracting from Landsat imagery the areas where rice is grown.

   a) In known areas having verified ground truth

      i) To determine geometric or spatial positions on a repeatable basis with a high degree of confidence. i.e., identify the same site on successive passes.

      ii) To determine the spectral signatures of rice at different stages of land preparation, planting, growing, and harvesting periods.

      iii) To determine temporal signature changes of a specific site with changes in time so as to distinguish rice from other spectrally similar plant growths or crops.

   b) In broad areas of unknown coverage lacking ground truth

      i) To determine the area planted to rice

      ii) To derive figures upon which volume of harvest might be estimated under some average condition.

2) To determine which measurements from Landsat data are meaningful in assessing the status of rice growth as well as the conditions of the rice area (moisture, vigor, maturity, harvesting, health, etc.)

a) To obtain and make use of temporal, spectral, multi-coverage signatures of rice and determine their interpretation of crop production.

3) To establish the feasibility of predicting yeild, assesing the efficiency of an irrigation system, and aiding other management input functions necessary for successful rice growing. Achieving these objectives with procedures which are cost effective can lead to greatly improved management of rice growth in the Philippines. Such information can be extended readily to most other areas of Southeast Asia.

To achieve the objectives above, the first step is to extract reliable spectral, spatial and temporal signatures from image data for the test site areas, as received from Landsat 1. These signatures must be carefully correlated with ground truth, so the correlation can result in development of recognition algorithms. This is particularly necessary, since the rice field conditions are so varied at any given time that signatures of rice areas as small as even a few Landsat pixels will be composite of many signatures, some of which could also be found in non-rice areas. This would create an error problem if recognition of a particular spectral signature is used generally. Alternatively to exploit the spectral signatures of the myriads of individual rice field conditions would become an overwhelming task, especially if it were to be accomplished solely by a man as the interpreter.

Even a moderately accurate inventory of the total area in which rice is grown, as determined from analysis of the image data, would be of considerable value. Also, a similar periodic inventory of the total area of rice grown within the benefited area of an irrigation system during the dry season would be most useful. In the latter case, the return on investment can be assessed for new (or additions to) irrigation systems. This, in turn, serves as a guide to new investments in irrigation systems.

Fortunately, at the time this project was commenced, there existed one instrument, the General Electric Multi-Spectral Image-Extraction System (GEMS) which could correlate imagery, extract signatures in histogram form, scan and identify those areas of similar or equal reflectance, summarize, tabulate and display such areas, and calculate the areas which have the same classification. The GEMS instruments involved near real time scanning of the imagery, using a three-channel TV sensor, and included a variety of electronic processing and display functions tied to a dedicated digital computer. System operation ranged from essentially automatic to an aided-manual mode.

Subsequent to the beginning of this contract, a new much more powerful instrument for correlation, analysis, and extraction of information from image data was developed known as the General Electric IMAGE-100. A limited amount of time became available on this machine at the close of this project. Details of the IMAGE-100 and its important application to this project are described subsequently. It has a powerful, flexible, spectral discrimination system which can greatly aid manual interpretation by systematically and rapidly examining characteristics of all individual pixels. The IMAGE-100 has even greater resolution than the nearly 9 million pixels per image received from each band of the ERTS/LANDSAT Multi Spectral Scanner (MSS). System operation can range from essentailly automatic to an aided-manual mode, and such operation is under the control of the operator/analyst who observes the system displays and

million pixels per image received from each band of the ERTS/LANDSAT Multi Spectral Scanner (MSS). System operation can range from essentially automatic to an aided-manual mode, and such operation is under the control of the operator/analyst who observes the system displays and outputs, makes judgements and communicates with the system via a control panel and keyboard.

III. ERTS/LANDSAT IMAGERY

Imagery obtained from Landsat I, formerly known as ERTS, the Earth Resources Technology Satellite, is derived from a scan of successive sectors of the earth approximately 200 km (118 statute miles) square as the satellite pursues its approximately North-South retrograde orbit at an altitude of 915 km (550 mi) above the earth. Successive "exposures" with a 10% end lap are made by four simultaneous independent scanners known as a Multi Spectral Scanner (MSS) which scan a given area.

The relationship between the MSS sensor wavelengths, and the so-called Band Code numbers are tabulated below:

Band Code No.	Wave lengths (Micrometers)
4	0.5-0.6
5	0.6-0.7
6	0.7-0.8 (very near infrared)
7	0.8-1.1 (near infrared)

From the taking point in the Philippines there is no line-of-sight antenna to receive the digitized scanned data. Therefore, the information is stored on a magnetic tape until it can be transmitted out to a receiving station in the United States. The exposures are all made at approximately 9:30 am over the useable visible portions of an orbit. The orbit is also arranged so that successive orbits will provide other passes with the result that a minimum 14% side lap coverage is achieved and the pattern then repeats every 18 days.

A. Magnetic Tape Data

The digitized scanned data of every "exposure" by the Landsat MSS scanner is transmitted by radio frequency from the onboard magnetic tape to the ground receiving station. As received the data is sorted on magnetic tape. This being the initial ground storage medium it is the most precise form of the data--several times more precise than the visible derivatives which are made from the digitized form. Up until the General Electric IMAGE-100 was used as described in Section VI the magnetic tape form of studying the data was not employed on this project.

B. Black and White Imagery

From the transmitted magnetic tape record NASA performs a massive adjustment program resulting in data which is then printed in a black and white record which is quite comparable to a photograph of the subject area in both tone and in geometric positioning of image detail. Each given geographic area of the earth is scanned by each of the MSS scanners. Consequently four black and white images are produced for each exposure. These are produced in several possible sizes. The basic 70 mm positive format becomes the archival copy. Copies of this are convenient as a browsing format to scan a large area for selection of prints to be produced at larger scale for detailed study. The 70 mm format is commonly enlarged 3.369 times and printed on 9.5 inch film which are at a scale of

1:1,000,000.

C. Color Composite

Color composite simulations from the 9 1/2 inch black and white imagery are produced by NASA as negatives or positives, transparencies or prints. It was found that for study purposes on this project positive transparencies were the easiest to use. For display purposes positive prints were best. Four bands of wave length frequencies of Energy emitted from the earth in four wavelength bands is scanned, but the human eye can only sample three colors and their combinations, and this does not include the infrared frequencies. Therefore, it is necessary to select which three of the four frequencies should be printed and in which colors and with how much intensity. The color composite transparencies which were used were printed with Band 4 data in blue, Band 5 data in green, and Band 7 data in red. Use of such positive color composite transparencies over a light table with variable brightness gave the greatest reduction, detection, and ease of identification and abstraction of data.

D. Imagery Received With Less Than 80% Cloud Cover

The following coverage of test areas in the Philippines was received. It is interesting to note that imagery was requested for any exposure which had less than 80% cloud cover. On more than one occasion an image with 80% cloud cover had a beautiful clear exposure of at least some of the test areas. Contrariwise on one test area no useful imagery was ever received.

Test Area	Date of Coverage	Comments
Nueva Ecija Peñaranda and Gapan	31 Oct. '72	Mag. tape rec'd.
	18 Nov. '72	Mag. tape rec'd.
	6 Dec. '72	Mag. tape rec'd.
	23 Dec. '72	Mag. tape rec'd.
	28 Jan. '73	Mag. tape rec'd.
	21 June '73	Mag. tape rec'd.
	23 Sept. '73	Not received in time to perform other than cursory man scanning
Bulacan	31 Oct. '72	Partial coverage
Angat	6 Dec. '72 23 Dec. '72	Partial coverage
Santa Cruz	None	

Unfortunately as will be noted under Section IV on Ground Truth the dates of planting in the test areas for the wet season vary between 5 and 20 June 1972 with harvest dates between 21 September and 11 October so imagery during the wet season was missed. For the dry season (irrigated) test areas the dates of planting in 1972 varied between 1 and 9 October with harvest dates between 2 and 14 March 1973. So the beginning and ending of the dry season, the most definitive periods, were missed. The imagery for 21 June 1973 corresponds to the beginning of a wet season. The 23 September 1973 image represents either maximum growth at the close of a wet season or just after harvest, which would be a time of complete difference showing bare ground. Depending upon the harvest rate on adjacent paddies an extremely varied, mixed bag, is displayed.

IV. GROUND TRUTH DATA

Ground truth has been of two sources slightly different but equally valuable. The sources are:

(1) Data produced by the International Rice Research Institute under the direction of Dr. Thomas H. Wickham, Associate Economist.

(2) The Agricultural Engineering Department, University of the Philippines, Los Banos, under the guidance of Professor Senen Miranda.

Actually, the ground truth data for each site consists of information for 6 to 20 paddies which are representative of the entire site. A site may contain 10 times or more the number of paddies which are completely inventoried. The election of specific paddies for inventory and the derivation of ground truth for a given test site is obtained by use of Thiessen networks. For initial analysis and correlation with the spectral signatures received from ERTS imagery, two quantities were selected and plotted against time to relate spectral signature variations: (1) a quantity indicative of plant growth or chlorophyll showing, or during harvest period indicative of the amount of rice plants still standing at a given date; and (2) a quantity which represents the soil moisture status or the percent of flooded paddies within the site.

A. International Rice Research Institute (IRRI) Data

Ground truth data such as in Figure 2, from the International Rice Research Institute, provides specific information for dates of orbit passes. The information identifies for each area items such as paddy number, age of the crop in days, fertilizer used in kilograms of nitrogen per hectare, plant height in centimeters, number of tillers in each plant, and the water status on the date of overflight. In addition, the final date of harvest and the yield in kilograms per hectare are listed.

B. University of the Philippines Los Banos (UPLB) Data

The type of ground truth data sheet submitted by UPLB is shown in Figure 3. This sheet identifies the test area and canal turnout location together with the area number, variety of rice planted, date of planting, fertilizer application in terms of kilograms per hectare of nitrogen, phosphorous, and potassium, types and extent of diseases, harvest date and yield in cavans per hectare. (Approx. 23 cav. = 1 ton, or 25.76 cav. = 1 metric ton or 1000 kg.)

C. Plant Growth and Water Status

For plant growth in the IRRI sites (San Nicolas, Malimba, Mahipon) the plotted quantity, Figure 4, is proportional to the products of plant height and stalks per square meter for the test paddies, and averaged over the entire site. In the case of the UPLB sites (Penaranda A, E, II, V), it is proportional to days after planting, since that is the only pertinent information available. Planting dates vary in each paddy, so an average planting date for each full site is determined. Similarly, harvest dates are different for each paddy. Sometimes the total harvest period for a site extends over six weeks. For the harvest period, then, the rice plant plot for a site shows the percent of total paddies where

SECOND CROP (dry season)

INTERNATIONAL RICE RESEARCH INSTITUTE
Manila, Philippines

Paddy No.	As of December 23, 1972					As of January 28, 1973					Date of harvest	Yield (kg/ha)
	Age of crop[1/] (days)	Cum. N use (kg N/ha)	Plant height (cm)	Tiller no.	Water status[2/]	Age of crop[1/] (days)	Cum. N use (kg N/ha)	Plant height (cm)	Tiller no.	Water status[2/]		
San Nicolas												
101	48	0	44	13	F	85	18	77	15	S	Mar. 2	4095
102	51	0	30	7	F	88	141	63	17	F	Mar. 14	3138
103	44	35	31	9	F	81	119	61	14	F	Mar. 14	3759
104	53	55	31	8	D	90	100	58	14	F	Mar. 8	3272
105	46	0	27	10	F	83	103	62	14	S	Mar. 9	4256
106	46	0	40	12	F	83	36	69	11	F	Mar. 8	3416
107	48	0	43	15	F	85	103	73	13	S	Mar. 9	5552
108	52	79	30	9	F	89	135	70	18	S	Mar. 8	5938
109	44	0	44	13	F	81	108	72	18	F	Mar. 8	5263
110[3/]	-	-	-	-	-	-	-	-	-	-	-	-
111	48	31	35	11	F	85	106	59	18	F	Mar. 9	4412
112	48	50	35	13	F	85	100	64	17	F	Mar. 9	4761
113	52	0	51	14	F	89	94	87	14	S	Mar. 7	4262
114	49	0	31	10	D	86	158	65	14	F	Mar. 9	5012
115	48	0	33	9	F	85	90	53	10	F	Mar. 8	3534
116	41	0	36	9	S	78	75	62	17	F	Mar. 14	4276
117	48	0	27	6	F	85	68	65	15	F	Mar. 9	5412
118	48	33	34	7	F	85	75	67	14	S	Mar. 8	4250
119	46	68	32	15	S	83	104	67	17	F	Mar. 9	5127
120	49	14	27	12	F	86	82	66	14	F	Mar. 8	4480
121	42	75	49	10	S	79	75	70	14	S	Mar. 7	5362
Malimba												
201	44	75	28	12	F	81	97	62	17	S	Mar. 9	2930
202	55	56	26	8	F	92	56	57	13	F	Mar. 9	4000
203	57	30	51	13	F	94	60	82	14	S	Feb. 27	3900
204	53	24	36	9	F	90	24	63	15	F	Mar. 7	2953
205	48	98	37	11	F	85	98	76	16	F	Mar. 7	4630
206	52	45	30	9	F	89	59	65	15	D	Mar. 9	3394
207	49	0	28	9	F	86	70	66	17	D	Mar. 9	3922
208	58	90	47	16	F	95	90	76	18	S	Mar. 8	3372

Figure 2. IRRI Ground Truth Data

FIRST CROP (WET SEASON), 1971-73

UNIVERSITY OF THE PHILIPPINES
Los Banos

ARIS, LATERAL E

Lateral/ Turnout	Stake No.	Variety Planted	Planting Date	Fertilizer (KG./HA.) Application N - P - K	Diseases Types & Extent	Harvest Date	Yield (cav./ha.)
E4B	1	IR20	6/18/72	30.0-30.0-30.0	--	10/6/72	64.0
1+860	2	C463	6/20/72	30.5-30.5-30.5	Bacterial Leaf Blight	10/11/72	50.0
	3	C463	6/17/72	6.8-6.8-6.8	-do-	10/10/72	48.0
	4	IR20	6/05/72	53.5-53.5-53.5	--	9/23/72	60.0
	5	C463	6/17/72	6.8-6.8-6.8	Bacterial Leaf Blight	10/03/72	55.0
	6	IR20	6/20/72	30.5-30.5-30.5	--	10/11/72	79.0
	7	WAGWAG	6/05/72	116.0-17.0-17.0	--	9/21/72	82.0

SCRIS, LATERAL A

Lateral/ Turnout	Stake No.	Variety Planted	Planting Date	Fertilizer (KG./HA.) Application N - P - K	Diseases Types & Extent	Harvest Date	Yield (cav./ha.)
A +240	1	C463G	7/01/72	65.5-6.0-6.0		10/25/72	74
	2	C463G	7/01/72	-do-		-do-	79
	3	C463G	7/01/72	-do-		-do-	83
	4	IR12	8/15/72	0 - 0 - 0		10/31/72	59.5
	5	C463	7/19/72	Submerged from August 1 to August 31			no harvest
	6	IR12	7/19/72				
	7	IR12	7/17/72	25.0-50.0-25.0		10/31/72	110.0

Figure 3. UPLB Ground Truth Data

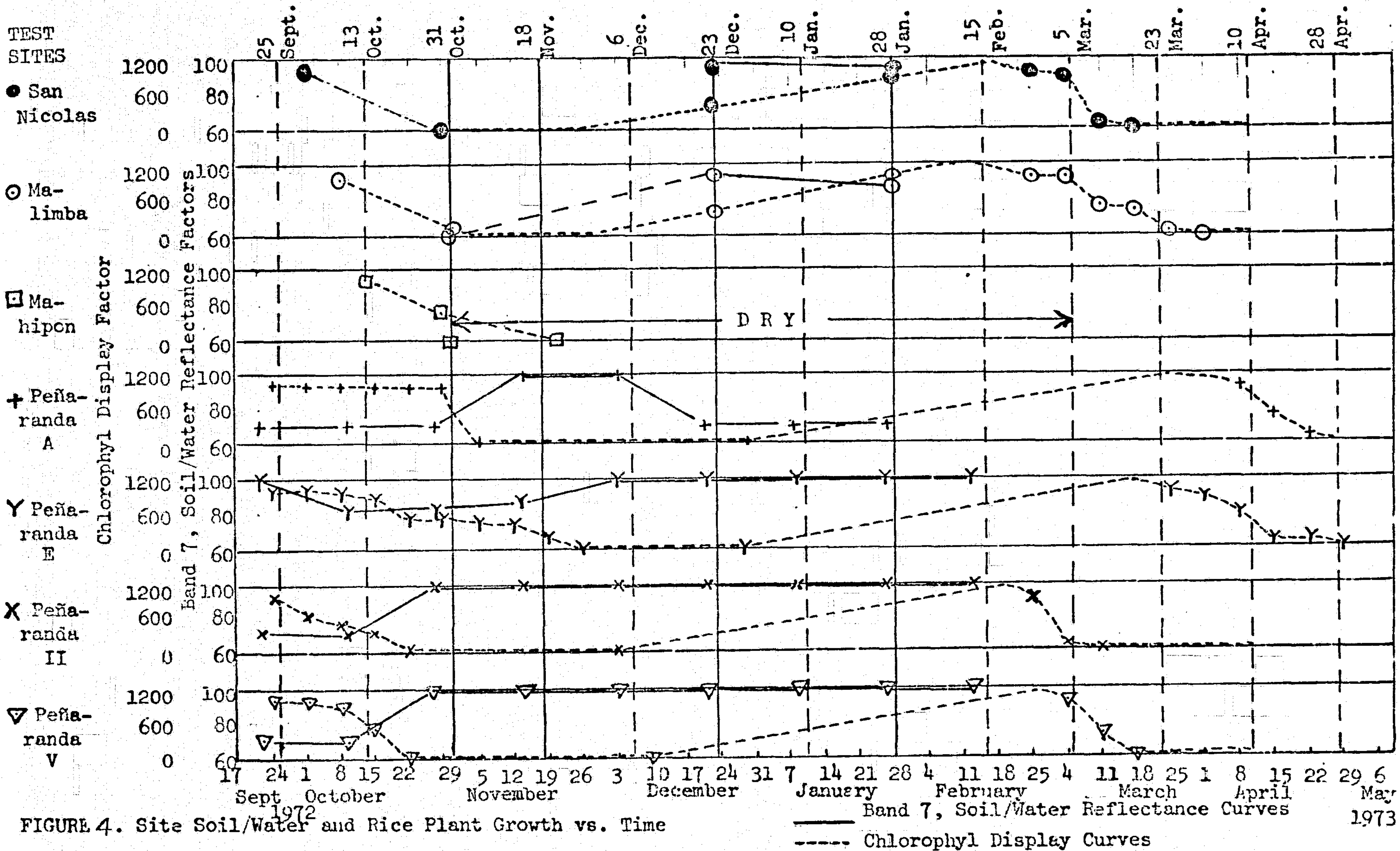


FIGURE 4. Site Soil/Water and Rice Plant Growth vs. Time

rice is still growing on any given orbit date.

The site water status plots are determined similarly. IRRI provided test paddy information for their sites in three discrete categories: Flooded; Saturated; Dry. These conditions have been arbitrarily weighted at 100, 80, and 60, respectively, and an average value for the full site at each sampling date has been computed and plotted. Water status information for the UPLB sites has been supplied to us in the form of "flooded" or "not flooded" for each test paddy. Here, these conditions were weighted arbitraily at 100 and 70, respectively, and an average value for the full site has been computed and plotted for each sampling date.

The plant growth is measured by Landsat as a strong display of clorophyll reflectance in infrared Bands 6 and 7 and a low reflectance in Band 5 (red). The water status of land flooding is displayed to Landsat imagery as a low reflectance in infrared Bands 6 and 7. The plant growth and water status or the chlorophyll/soil moisture display vs time for each of seven sites, determined as described above, are presented in Figure 4.

Comparisons can now be made of the temporal variations of the display factors vs. single-band mean radiation intensity for each site as extracted from Landsat data. First, some general observations can be made. In preparation for a new crop, stubble on the sites may be burned (not always), the paddies are flooded and then plowed. During this period, site responses in all MSS bands can be expected to drop, reaching their lowest values just prior to planting when paddies are flooded but with no plant growth. From planting to a few weeks before harvest, there should be a rise in site response in Bands 6 and 7 and a fall in Band 5 as the rice plants grow. About three weeks prior to harvest, the paddy flooding is stopped and the rice plants become drier. During this period there usually is a rise in Band 4 and 5 responses and a slight drop in Bands 6 and 7 due to drying of the crop stalks. During harvest a further drop in site infrared response in Bands 6 and 7 occurs as bare soil is exposed. After the harvest is complete, but before preparation for the next crop, especially if this coincides with a period of low precipitation, there is a rise in site responses, particularly in Bands 4 and 5, as the bare soil and stubble continue a drying process. Weed growth may modify the spectral reflectance from a site.

V. DATA ANALYSIS FACTORS

In analyzing the satellite image data, three aspects of the data should be considered - spatial, spectral and temporal. A few comments on these three, particularly with regard to machine aided analysis, are presented here.

A. Spatial

First, it is noted that the Landsat spatial resolution is slightly in excess of one acre, or somewhat less than 0.5 hectare. Individual rice fields often may have dimensions which render them only a few Landsat resolution elements (pixels) in width - perhaps only one or two. And, the status of rice from one field to the next frequently will differ.

Test site areas studied in this program consist of many such rice fields and each test site is thus a heterogeneous grouping of rice conditions and, correspondingly, of rice signatures. In this situation, the Landsat pixel size surely must be considered in image data analyses (i.e., What are the implications of pixels straddling field boundaries? Should there be classification only of areas which are larger than perhaps 3x3 pixels?)

Carefully locating each area of interest in the scene is obviously important under the conditions just described. This is especially true when the analysis concentrates on extracting signature information from the image data for a test site whose location is indicated on a map. If the expected vs. actual site locations differ by only a few pixels, extracted signatures can be in error since they will include adjacent fields where conditions may differ from those in the test site area. A similar situation arises when signatures for the same location or site are to be compared for two or more satellite overflights. Temporal signature changes will be in error if each member of the temporal data set does not pertain to the same geographic location.

To locate particular fields in the image data for the Southeast Asian environment is a difficult problem (Probably encountered much less often, incidentally, in the analysis of agriculture in the middle and western United States). In order to achieve location accuracies of a few pixels, the analysis must depend upon location information relative to pixel reference points in a scene. Establishing and recognizing an adequate number of these points in the Southeast Asian image data, where rice paddies are generally less than ten hectares in area, is not usually a simple matter.

Registration of image data also is related to matters of spatial resolution, location accuracy and the small size heterogeneous nature of rice fields. When analyzing color composite transparencies, it must be recongized that these are produced from black and white single-band transparencies which have been manually registered to perhaps one or two pixels in each direction. This leads to extracted signature errors for small locations. The situation usually is improved when digital data are used. But, when the analysis proceeds to an examination of

the same location for image data from two or more satellite overflights, a temporal rather than a band-to-band registration problem exists. This may be handled in local areas by locating positions relative to reference points in a scene. For cases in which it is desired to produce temporally composited digital data for a scene, the analysis must consider that the satellite orbit changes slightly with time and a rotation error, unless corrected, will exist within the temporally composited data.

B. Spectral

Consider now some of the spectral-radiometric aspects of the data. When color composite transparencies are analyzed, data from only three of the four available spectral bands are used and, in general, no more than 32 intensity levels (more likely, 16) are distinguishable in each band. These levels must be referenced relative to the step wedge in each transparency in order to compare extracted signatures from one transparency to the next. The situation is similar for single-band black and white transparencies, except that all four bands may be analyzed, and possibly the number of resolvable intensity levels in each band exceeds that for the color composite. When digital data is used, four bands of data may be analyzed simultaneously if desired, and up to 128 intensity levels for the data in each band may be employed when appropriate.

C. Temporal

With regard to temporal data analyses in this investigation, a maximum of five dates spanning the period 31 October 1972 to 21 June 1973 existed in which there were useful satellite data available. Cloud cover in some cases reduced this number to two to four. Temporal data can be expected to be important in the analysis of agriculture, particularly in the Southeast Asian environment where the cycle for rice site preparation, transplanting, crop growth and harvesting may occur in a 13-17 week period. The cycle will repeat at a later time during the year if there is both a wet season and dry season rice crop. Six, possibly seven, Landsat overflights would occur during each cycle, but cloud cover can reduce the number of these for which useful data is available for particular locations.

VI. DATA ANALYSIS METHODS

Each "exposure" from Landsat provides in excess of 100,000,000 bits of information. The analysis of this amount of data for each image constitutes a formidable task. It is a larger task than a man can perform without some assistance. Even if a man selectively determines to work only with say 1/1,000th of the bits of information presented he still faces a herculean task. At that same time he increases his problems of knowing just which bits of information should be selected for each particular task and how he can identify the location of those particular 100,000 bits.

In this project efforts were made to sample several representative methods of analyzing the data. These varied from using the human unaided eye and interpretability, with nothing more than a magnifying glass, to using the sophisticated electro-optical-mechanical instrument--the General Electric IMAGE-100--in a man-machine interactive system.

Six systems were tested on the Philippines rice identification project to a greater or lesser extent. The first four systems with a person as the primary sensor and with nothing more than various optical-mechanical magnification schemes will be described briefly. These schemes--or instruments--enlarge some group of bits of information until they are large enough to be recognized by the operator as having a particular location and significance at that location. Various color assignments are used to "alarm", to attract attention, or to enhance the view and improve interpretability. Some of these are quite effective expecially as an operator works with that system long enough to train his abilities to react in a particular manner. Details of these simpler, less expensive, less precise systems will not be described at length. Many other principal investigators have conducted more elaborate testing programs both on Landsat imagery and on other types of imagery than were performed herein.

Of greater interest are the results of tests using the man-machine method where an electro-optical-mechanical instrument samples the data of a particular group of bits of information. The instrument relays details of analysis of this group of perhaps from 10 to 10,000 bits and also reveals the existence of other similar areas in the total scene. The GEMS or General Electric Multispectral Image Data Extraction System was one of the best man-machine systems available at the time this project was proposed. At that time it was fully expected to use GEMS for all the sophisticated analysis expected on this "rice" project. However, the analysis of rice in tropical areas turned out to be more complex than expected. Fortunately the General Electric IMAGE-100, state-of-the-art instrument, came on line at an appropriate time and analysis periods on it were made available to this project. Use of all these instruments is detailed below.

A. Human With Unaided Eye

After the spectral reflectance of test areas at each time of coverage had been obtained from the GEMS studies of known test sites (see Sec. E. below) an attempt was made to perform an analysis of an area approximately

50 km square, including the Peñaranda-Gapan Test Sites area, to determine the location of areas planted to rice. It was known at the outset that all areas are not planted to rice on the same date, or even within the same month. Also, the same variety of rice is not universally planted. Thus the spectral reflectance of rice areas on color composite transparencies may vary greatly over the transparency or in sequences of imagery from successive satellite overpasses, yet all may be rice. It is not possible to look at any one image resulting from a single overpass and detect all the rice growing areas on it. This was discovered and proven with GEMS. However, it was only as IMAGE-100 came on line (see Sec. F below) that an instrument with adequate capacity and memory became available to really identify a temporal growth pattern.

It is necessary to have a minimum of three or four well-timed images of the desired area for study. The original muddy or watery black display of the site preparation area at the time of plowing and planting might be considered the initial coverage. It has a distinctive color and tone except that it might be confused with mud flats and some types of swamps--reasonally devoid of vegetation. Successive images reveal increasing reflectance in the infrared frequency--increasingly red in the transparency false-color--for approximately 90 days at which time drying occurs and the tone lightens approaching a beige color. As harvesting begins less chlorophyll and more bare earth reflectance is displayed. As the rice approaches its maximum chlorophyll display it might be confused with vegetable crops--most of which have a shorter growth sequence--or even with mango trees--which frequently are grown in the same 50 km area and which have a strong infrared (chlorophyll) display.

The problems of dealing with the complexities of different planting times, different dates and spacings of 18 days or multiple 18 day imagery samplings, as well as with strains of rice which mature with different numbers of growing days, variations in appearance due to water and weather occurrence, and others become exceedingly complex. It is possible finally for an individual to determine for a specific local area whether rice is grown or not. The determination is laborious and subject to many fringe-type decisions. It was not possible to run a statistical survey of the accuracy of identification. The rice growing area that could be identified by a person in a given period of time is so small compared to needs and compared to the rate obtainable by a man-machine method (see Sec. F below) that further efforts by the unaided human were halted.

B. Human With Zoom Transferscope

The Bausch and Lomb Zoom Transferscope is a most convenient sketch master type of instrument for providing a variable magnification, such as of the color composite transparencies and projecting the viewed area onto a sheet, such as a map, so detials may be transferred.

In analyzing the spectral signatures for the Gapan Test Region on the color composites of the ERTS imagery, a problem arose as to where on the ERTS imagery the twelve test site locations within the Gapan area were located. The twelve test plot boundaries were supplied to Cornell on quadrangle maps of scale 1:50,000 by the University of the Philippines and the International Rice Research Institute.

In the initial attempt to depict the test site locations for General Electric to do the analysis, a peripheral line was drawn on the imagery containing all twelve Gapan test areas. A xerox copy of the same twelve plots from the quad sheet was included for reference. This peripheral line was obtained by superimposing the ERTS imagery onto the 1:50,000 quad sheet at the same scale on a Zoom Transferscope.

Even though the quad sheet and peripheral line proved to be inadequate, G.E. was able to send back to Cornell enlarged polaroid black and white prints in the region they believed to be the test plots. There were two inherent problems with exact location of the test plots. First there was inadequate information for exact location of the center of each of the test plots; and secondly based upon the detailed agricultural information supplied by the Philippines there seemed to be a discrepancy between the information supplied from the imagery, and for the same time period, the information supplied from the ground observations.

A second attempt at more precise location of each of the twelve test plots at Gapan was based on three separate coordinate axes. Three separate, easily depicted, well defined points near the twelve test areas were established on the enlarged polaroid prints and pin-pricked for identification. These three points served as origins for three separate coordinate axes. The ordinate axis was defined as a line of longitude. From each of these origins, the twelve individual test plots received three separate coordinate values. Three separate coordinates were deemed necessary because of measuring error, questionable selection of origins too distant from certain test plots, and safety in numbers in case of cloud cover in future exposures of one or more origins. The center of each of the test plots was pin-pricked for identification, and along with their respective sets of three coordinate values, were returned to G.E. It was estimated by G.E. that the initial peripheral location of the test plots resulted in an error of around 1000 feet. With the coordinate axis approach it is estimated that the discrepancies have been reduced to as little as 300 feet for more favorable plots and 800 feet for those less favorable. Favorable is used in the sense of final location on the imagery using all means of identification, i.e.: nearness to predominant features such as roads and rivers, size and shape of the test plot, and spectral analysis as a function of harvesting or irrigation status.

One final attempt at more precise location of the Gapan test areas incorporated an unknown but easily identifiable orthogonal cross that appeared on the 1:40,000 scale polaroid prints. Each of the twelve plots were referenced to the center of the cross, again a line of longitude serving as the ordinate.

C. Human With Multisprectral (I^2S) Scanner

A limited amount of work was performed with an I^2S Multispectral Scanner. Considerable experience is required to obtain definitive results. A principal problem encountered was the difficulty of remembering a color selected or set for a particular color of spectral display to represent a particular event and then of being able to reproduce that precise color again at a later time. The freedom to make color displays enabled nice pictures to be made, but it seemed to complicate precise

spectral analysis especially when precise geometric positioning of every pixel of an image was the ultimate goal.

D. Human With Diazo Transparencies

Diazo enlargements at a scale of approximately 1:100,000 were experimented with to determine how much additional information could be derived from such enlargements. Again the problem arose of obtaining and retaining specific colors for sepcific events particularly when different dates of imagery had to be compared for different stages of growth and the geometric position of each was critical. This method of magnifying imagery data for abstracting land use information has been successfully used at Cornell.* It is a relatively inexpensive method of obtaining large masses of information in broad categories when geometric restrictions are not limiting.

E. GEMS** Man-Machine Interactive System

During the initial phases of this investigation much of the machine aided analysis was performed using the GEMS facility at the General Electric Valley Forge Space Center. Later in the course of this program, the General Electric Image 100 analysis system became operational at the G.E., Beltsville, Maryland facility and was used for data analyses. Image 100 is a state-of-the-art analysis system which evolved from and superseded GEMS. GEMS is no longer in operation. For this reason, only the key or unique aspects of the data analyses using GEMS will be discussed here.

GEMS is a hybrid analog-digital system used to analyze imagery which is input in transparency form. It involves near real-time scanning of transparencies using a 3-channel TV sensor, and includes a variety of electronic processing and display functions. GEMS is tied to a digital computer. System operation can range from nearly automatic to an aided-manual mode, and such operation is under the control of the operator/analyst who observes the system displays and outputs, makes judgments, and communicates with the system via a control panel and keyboard.

As noted previously, GEMS was designed to work with imagery inputs in transparency form. For the case of the color composite transparency, a radiometric calibration is performed in which the 32 GEMS-measured intensity levels in each of three bands are related to the steps in the 15-step gray wedge in the color transparency. In an attempt to keep signatures as simple as possible, yet sufficiently detailed to do the job, 30 of the 32 GEMS measured intensity levels in each of three bands were combined so as to produce only five larger increments of six GEMS levels each.

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*"Enhancement and Evaluation of Skylab Photography for Potential Land Use Inventory-Final Report," E.E. Hardy, et al., July 1975, NASA Report NAS 9-13364

**General Electric Multispectral Image Data Extraction System

Usually, this consisted of GEMS levels 3 - 8 for the first increment, levels 9 - 14 for the second increment, etc. The result is a 5x5x5=125 cell 3-D color space which is illustrated in Figure 5. An extracted 3-D signature in this system, for a scene area involving several pixels, consists of the percent of total pixels being analyzed which fall within each of the 125 color cells. Each color cell is designated by its quantized location along the three spectral axes, with larger numbers referring to a higher radiation level in that channel. For example, cell 1-3-5 corresponds to radiation which is simultaneously at the lowest level in channel 1, at the middle level in channel 2, and at the brightest level in channel 3. In the GEMS case here, channel 1 pertains to "green" in the transparency, channel 2 to "blue", and channel 3 to "red". In turn, these channels pertain to the MSS spectral bands in accordance with the preparation of the color composite - usually blue for MSS band 4, green for band 5 and red for band 7. Figure 5 shows the location of color cell 4-4-3.

When single-band black and white transparencies are analyzed, an analogous calibration procedure is used but there is, of course, only one coordinate axis for the gray level cells for each transparency where there were three coordinates for a color cell pertaining to the color composite transparency.

In order to extract 1-D or 3-D test site spectral signatures using GEMS and, respectively, single-band black and white and color transparencies, it is necessary that a test site electronic, binary map be constructed and stored in the system. This is accomplished by the analyst who manually enters a "1" or "0" in the appropriate elements of a 512x512 electronic storage array (a binary map) and registers these with the scene being analyzed. He does this through study of a map of actual site locations while also veiwing the GEMS display of the scene. The "1" elements in the 512x512 array are selected to approximate the boundaries of each test site and all of the area within those boundaries. The procedure is not exact, but for GEMS the stored boundaries are estimated to be within two or three Landsat pixels of where they should be. For small sites, any greater deviation could affect the quality of extracted signatures, particularly if rice field conditions outside the site boundary are different from those within.

The electronic site map is used to gate electronically the GEMS measured signals corresponding to the single or multiple band intensity level (s) for each Landsat pixel. Consider, for example, test site X which contains 100 pixels of satellite data. GEMS extracts from the color transparency the multispectral signature for site X and identifies where each of these pixels falls in 5x5x5 color space. The result is a 3-dimensional histogram signature for the site. When analyzing a single band black and white transparency, the procedure is analogous except that a 1-dimensional histogram is obtained. The analyst may then examine only the mean value of the histogram signature, or the entire spread of data in the signature, as the situation dictates.

Test sites can be expected to be heterogeneous. Recognizing this, an approach was made toward synthesizing 3-D signatures for features (i.e. conditions) within each site. This was accomplished by first devoting considerable study to the GEMS color display portions of several Landsat frames, along with careful correlation with available ground truth.

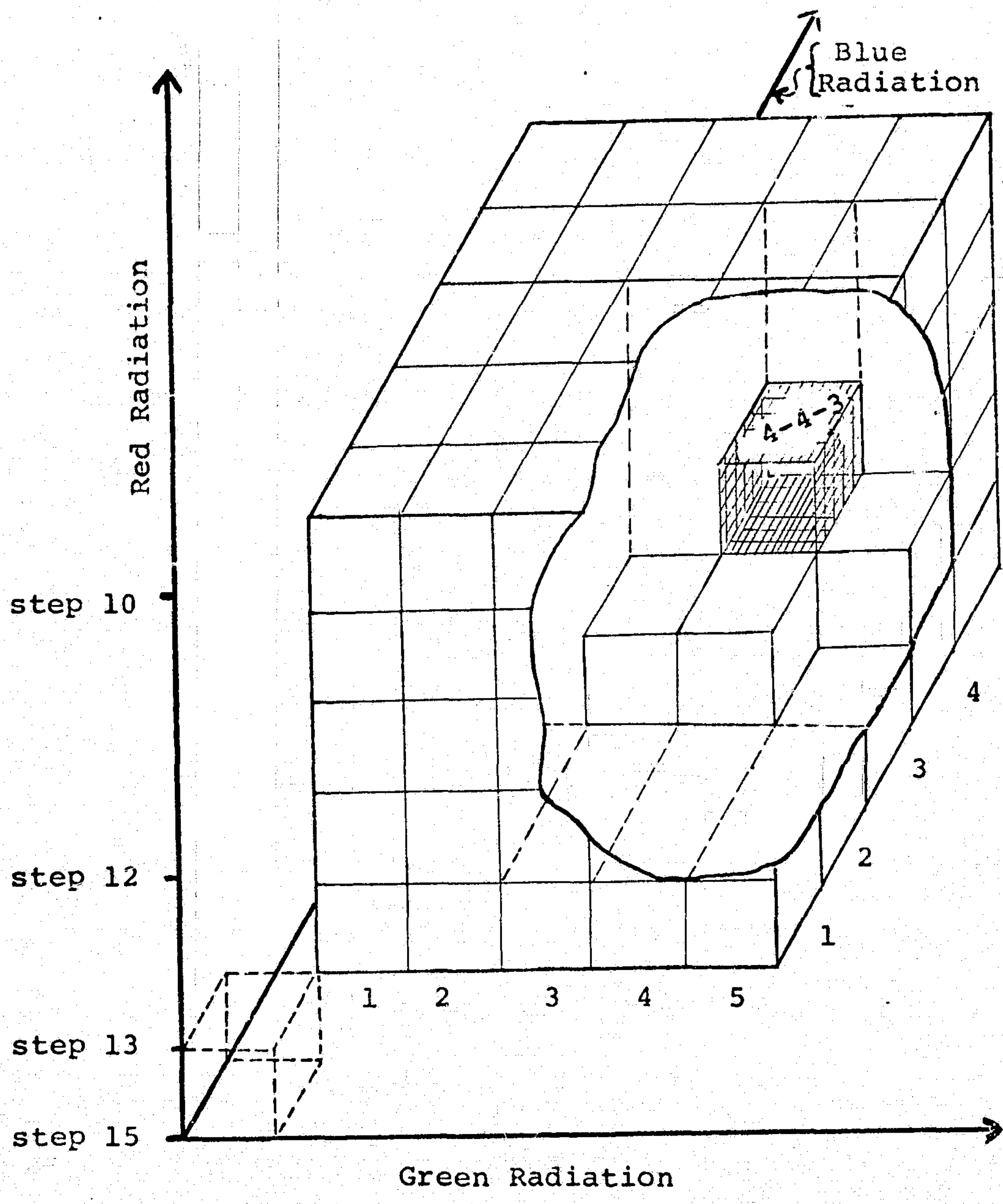


FIGURE 5. 125 Cell 3-D Color Space

Upon study of the display, it became apparent that seven frequently occurring colors could be distinguished visually: dark blue; blue; bluish pink; light beige; dark red; red; and pink. (White, such as in clouds, and black, such as in ocean water or cloud shadows, also are distinguishable, of course). These seven colors change somewhat with adjustments in the color display and with different preparations of a color composite, but seven distinguishable colors will exist in nearly all cases.

The study of the color display and ground truth then led to an estimated association of each color with a particular condition in the scene. These estimated relationships are shown in Figure 6. It should be noted that "red" in the transparency and display stems from MSS band 7 satellite data, "green" from MSS band 5 and "blue" from MSS band 4.

Each of the seven "colors" corresponding to a particular condition at a site really is a spread of colors involving a cluster of color cells in 5x5x5 color space. These were determined after considerable analysis, and the locations of these "colors" in color space is shown at the left in Figure 7. Note, for example, that "dark blue" is represented by nine color cells: 1-1-1, 1-2-1, 1-3-1, 1-2-2, 1-3-2, 2-2-1, 2-3-1, 2-2-2, and 2-3-2.

When a site 3-D histogram signature is extracted from the imagery using GEMS, the system output lists (in a computer print-out) the percent total site pixels in each color cell. A typical histogram signature is presented at the top right in Figure 7. Finally, by comparing the occupied color cells against those corresponding to the seven different site conditions, the percentage mix of features (conditions) at a site may be estimated. This illustrated in Figure 7 at the lower right, using the site histogram signature data from the example at the top right.

F. IMAGE - 100 Man-Machine Interactive System

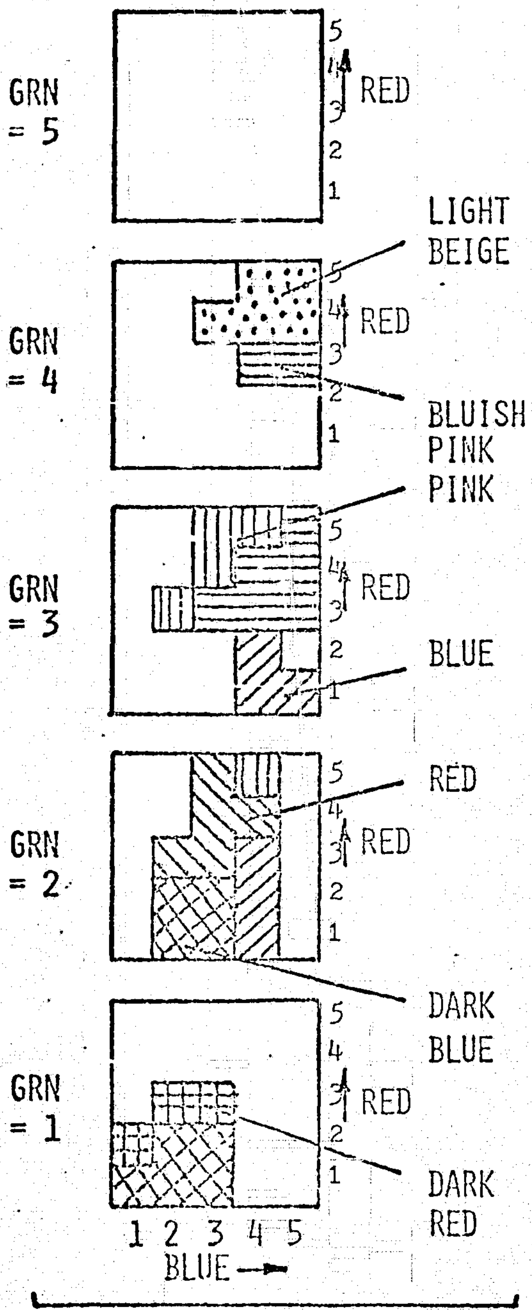
The General Electric Image 100 analysis system is a state-of-the-art, all digital, near real time man-machine interactive system. It consists of digital tape units; a dedicated digital computer; an image analysis unit; a color display; a data disk for display refresh and for high speed access to stored scene or analyzed data; an output printer; a computer terminal with keyboard, display and hard copy printer; and numerous controls for various analysis procedures initiated by the operator. For this investigation, image data input is via digital tape (Landsat CCT's), although a separate unit of the system enables entry of image data in transparency form.

A description of the Image 100 system will not be provided as a part of this report. However, a brief description of certain system operations and terminology is included in Appendix I. It may be noted that the Image 100 system, while continually undergoing improvements, is an image data analysis system in production by the General Electric Company. One model of the system is in operation at the General Electric Earth Resources Image Processing and Analysis Center (IMPAC) located at the G.E. facility in Beltsville, Maryland. At IMPAC, the Image 100 and other processing and analysis functions are operated as a service facility for a broad range of image data users. All of the Image 100 analyses pertaining to the investigation reported here have been performed at IMPAC in the Beltsville facility.

ESTIMATED COLOR SIGNATURE PROFILE FOR PHILIPPINE RICE

RICE SITE STATUS	DARK BLUE	BLUE	BLUISH PINK	LIGHT BEIGE	DARK RED	RED	PINK	TIME (WEEKS) (DRY SEASON)	
FLOODED; JUST PLANTED	X								
EARLY GROWTH + WATER	X		X		X	X			
50% GROWTH					X	X		11-14	
JUST PRIOR TO WATER CUT-OFF						X			
JUST PRIOR TO HARVEST						X	X		20-24
MID-HARVEST	X	X	X	X		X	X	1-7	
100% HARVESTED	X	X		X					
POST HARVEST, PRIOR TO FLOODING		X	X	X				5-7	
FURTHER POST HARVEST - NO FLOODING OR PLANTING (RAINFED BARRIO)			X	X					

Figure 6.



SITE COLOR FEATURES IN COLOR SPACE

3-D HISTOGRAM SIGNATURE FOR TYPICAL SITE			
COLOR CELL			% SITE POPULATION
G	B	R	
1	2	2	9%
2	2	2	7%
2	4	2	36%
3	4	2	28%
4	4	4	8%
4	5	5	12%
			100%

SITE FEATURE MIX		
DARK BLUE	BLUE	LIGHT BEIGE
9	36	8
7	28	12
16%	64%	20%
BARE SOIL VERY MOIST	MOIST SOIL	DRIER SOIL

Figure 7. 3-D Histogram Extraction

Figure 8 is a photograph of the Image 100 display, as viewed by the analyst, as the system presents a three-color display of Landsat digital multispectral scanner data for the region near Gapan for 31 October 1972. MSS band 4 is presented in shades of blue, band 5 in shades of green, and band 7 in shades of red. Although the data is stored in the system in four bands with up to 128 intensity levels each, the display itself is limited to presenting only three of those bands at a time and, of course, less than 128 intensity levels. The field of view for the displayed scene is approximately 30 km x 30 km (18 miles x 18 miles), and includes 512 x 370 Landsat pixels. The 31 October 1972 date falls near the end of the wet season rice harvesting period. Rice yet to be harvested, as well as other standing vegetation appears in the figure in shades of pink and red. Many of the blue areas in the scene pertain to locations where harvesting is complete and sites are being prepared for the dry season crop.

Figure 9 also is a photograph of the Image 100 display for the same scene as in Figure 8, but different information is presented. The multi-color, multi-level digital scene data are not shown; instead three themes* are presented, each in a different color. First, in yellow-white, the areas pertaining to eight test sites (where ground truth data are available) are shown as a single theme near the center of the scene. A second theme, in orange, consists of a series of small square marks showing the location of two rivers in the scene. These are used for geometric reference purposes. The third theme, in blue, shows the areas where there is considered to be a particular degree of moist, bare soil associated with site preparation after wet season harvest. Specifically, it pertains to areas having the same spectral signature as one of the sites (Peñaranda II) where it is known that moist bare soil exists. This third theme is the result of an Image 100 analysis in which the signature for Peñaranda II was extracted (using the site theme and the stored digital MSS data), and other areas in the scene were alarmed* if they exhibited a similar signature. The data contained in the first two themes was manually entered by the analyst as he carefully observed the displayed scene in color and referred to ground truth (site) maps.

Each theme may be independently (or in combination) stored, recalled, displayed in any color, or used in analysis at the discretion of the analyst.

The test site and river reference themes were output in hard copy via the Image 100 printer. The result is shown in Figure 10. Annotations labeling rivers, test sites, Gapan town, and showing North direction and map scale, have been added. The site themes exhibit some "tearing" of the stored theme data at the time of the printout. This indicates some Image 100 performance degradation for that particular moment - a condition subsequently corrected and not present during analysis. Note that the scales are different in the horizontal and vertical directions. This is due to the over-sampling of MSS data in the cross track direction such that it takes (n+m) Landsat pixels side by side cross-track to cover the same distance as n pixels along-track. This condition can be compensated in the system when necessary.

*See Appendix I

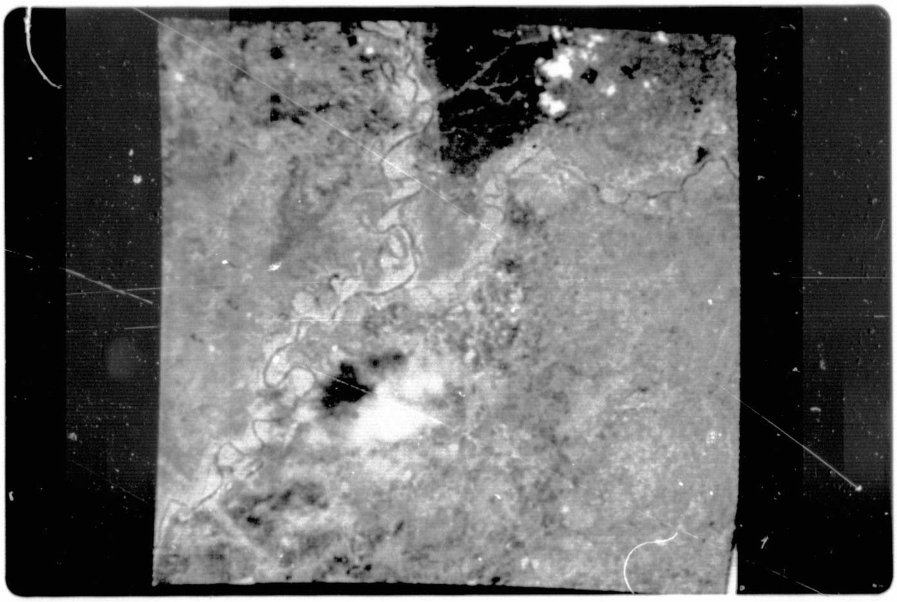


IMAGE 100 FALSE COLOR DISPLAY OF GAPAN SCENE FOR 31 OCTOBER 1972
(APPROXIMATE FIELD-OF-VIEW: 18 MI. x 18 MI.)
FIGURE 8

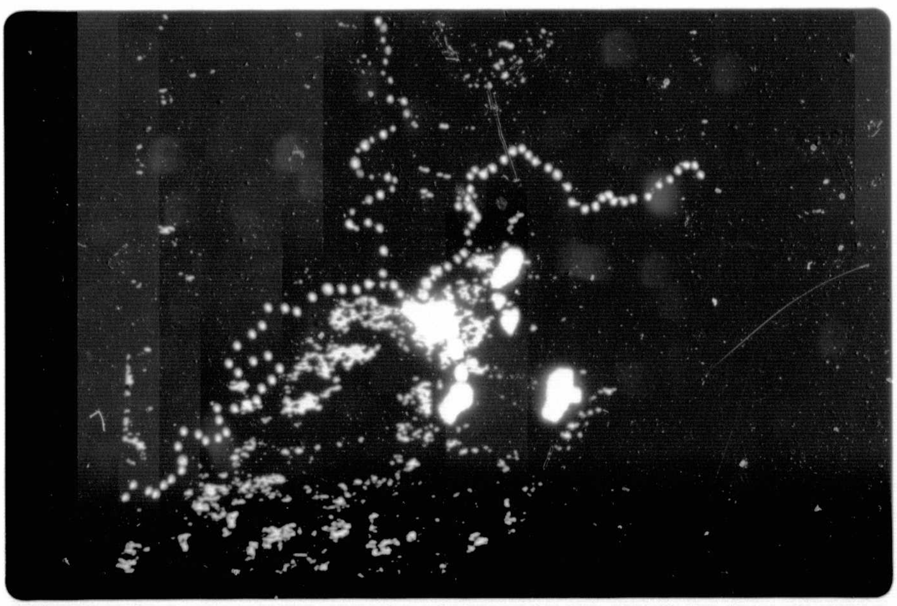


IMAGE 100 FALSE COLOR DISPLAY OF THREE THEMES
PERTAINING TO THE GAPAN SCENE FOR 31 OCTOBER 1972
FIGURE 9

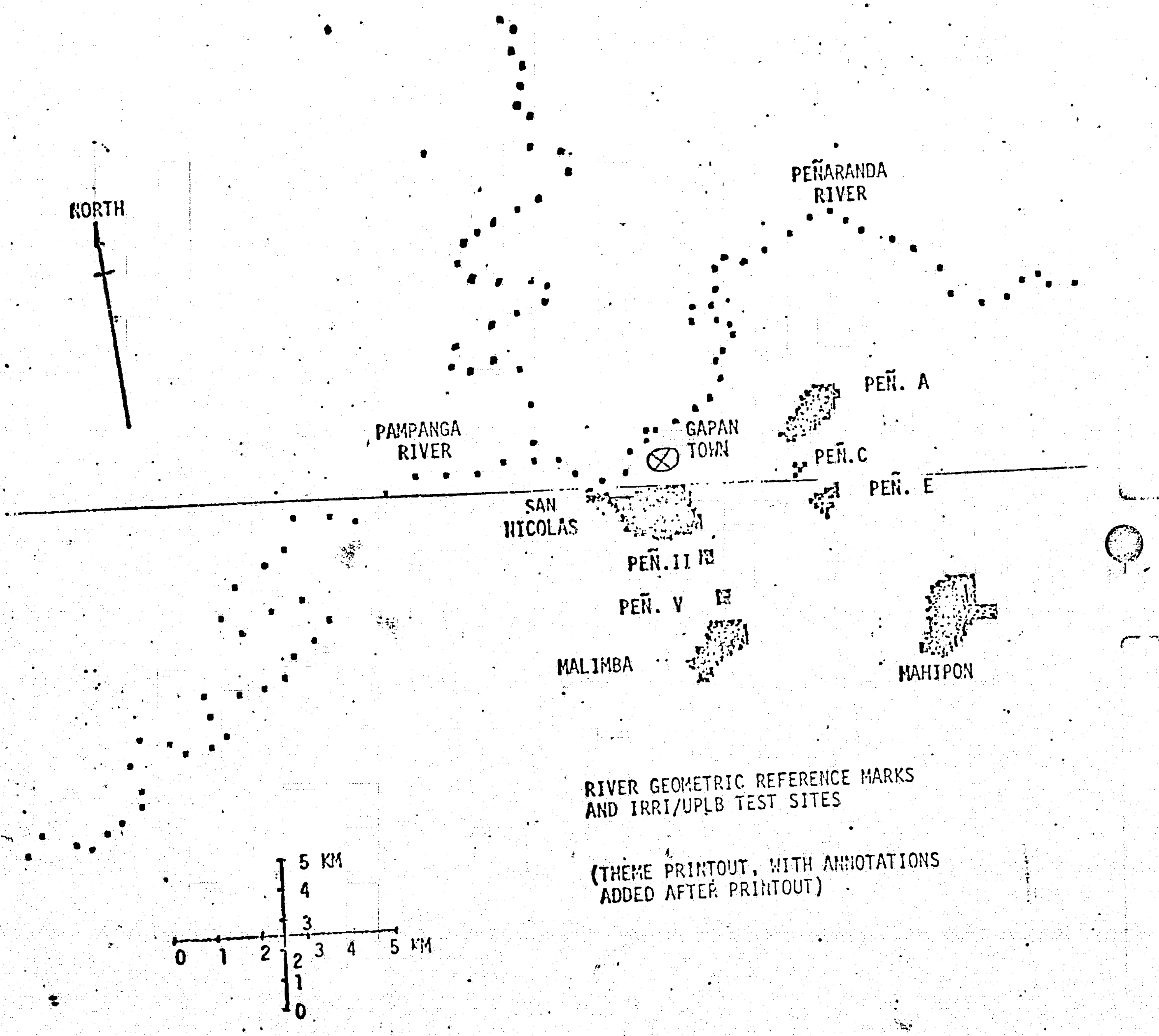

NORTH
PEÑARANDA
RIVER
PEÑ. A
PAMPANGA
RIVER
GAPAN
TOWN
PEÑ.C
PEÑ. E
SAN
NICOLAS
PEÑ.II
PEÑ. V
MALIMBA
MAHIPON
5 KM
4
3
0
1
2
3
4
5 KM
2
1
0
RIVER GEOMETRIC REFERENCE MARKS
AND IRRI/UPLB TEST SITES
(THEME PRINTOUT, WITH ANNOTATIONS
ADDED AFTER PRINTOUT)

Figure 10

Consider now histogram signature data which can be extracted from the Landsat four-spectral-band MSS digital data. The scene area to which the signature data applies may be a test site (using the test site theme) or it may be any other area selected by the analyst. Figure 11 shows the Image 100 hard copy histogram signature output for the San Nicolas test site for the Landsat overflight of 21 June 1973. Channel identification and abscissa scale minimum and maximum values were added subsequent to the printout. The abscissa in each plot pertains to the signal intensity level. In this case the radiometric resolution for analysis was set such that the minimum and maximum possible signal levels would appear respectively as 0 and 63 (corresponding to 0 and 127 in the source data).

The ordinate in each plot has a full-scale value of 100 (relative units). The histogram peak is set at 100, and the remaining elements are shown with proportionate heights.

The printout indicates there are 597 pixels in the training (test site) area, and each histogram should, therefore, be comprised of 597 pixels. These are one dimensional histograms and represent a look at the same 597 pixels in each of the four MSS bands. They result from a so-called "1-D" training process in Image 100 which is actually a signature extraction in 4-space*. The vertical dotted lines in each histogram show the minimum and maximum intensity levels exhibited by the training area pixels in that band. Note that the mean intensity level in each band as with most histograms is not necessarily centered between the limits. Image 100 computes the mean intensity value and the variance in each band for the training area sample, and these are listed in the printout along with outer pertinent numerical data.

In the course of the total analysis of image data using Image 100, 1-D histogram signatures were acquired for many test sites and other training areas in two lowland rice regions (Gapan, Angat) and for four Landsat overflights on 31 October 1972, 28 December 1972, 28 January 1973 and 21 June 1973. The signature mean values for many of these cases are plotted in Figure 12. Plotting was arranged to show two-band mean value signature points for MSS bands 4 and 5 jointly, and for MSS bands 6 and 7 jointly. That is one point in either of the two data sets corresponds to two of the mean value numbers from a single histogram signature extraction (such as in Figure 11). The data in Figure 12 suggests a fairly good correlation between MSS bands 4 and 5 and between bands 6 and 7 for the scenes and conditions investigated in this program.

As a consequence, although four-band data was usually extracted from the image data, many analyses in this investigation were studied and summarized on a two-band basis (i.e., MSS bands 5 and 6).

Return now to Figure 11 and the 1-D histogram signature plots for the San Nicolas site for 21 June 1973. Similar histogram plots were obtained using Image 100 for seven Gapan area test sites for that date. Each histogram printout contained numerical listings for mean intensity level and variance in each band.

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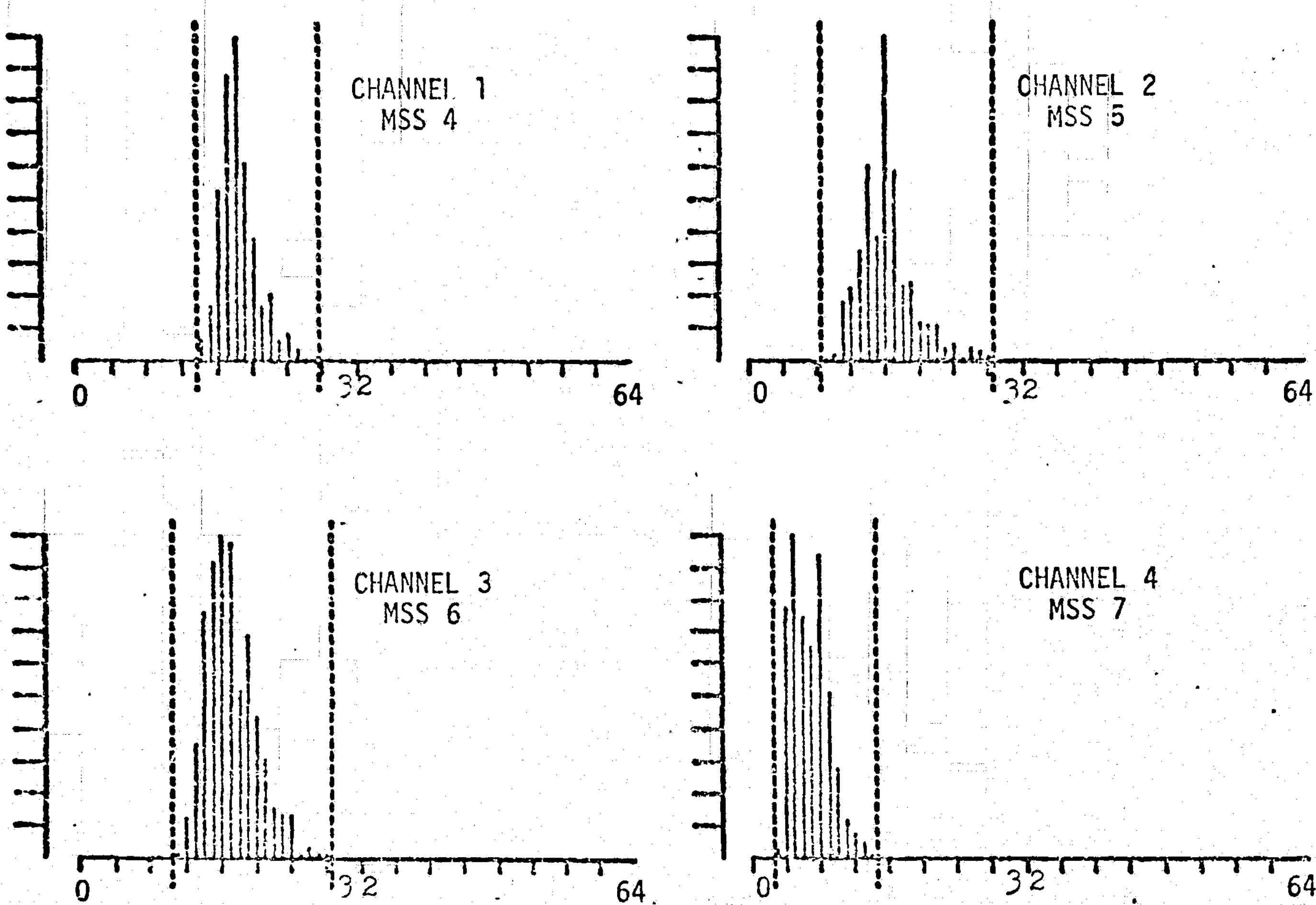
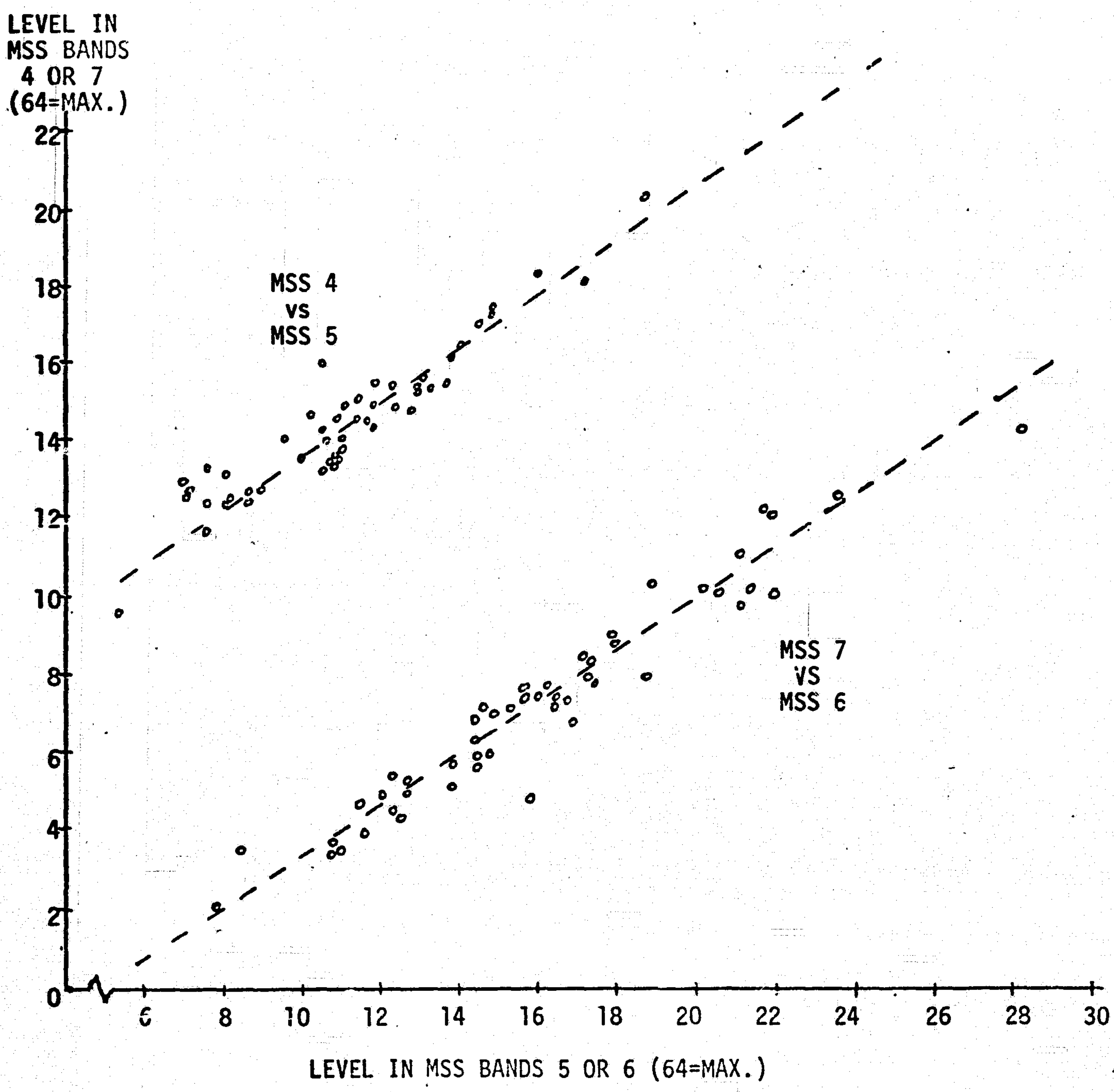
*See Appendix I for 1-D training and for N-D training. N-D training is available in Image 100 and is more powerful than 1-D, but it was not felt necessary to use the N-D capability in the present investigation.




```
      $$$ OVERVIEW $$$           +
#  LB  UB  DEL   PEAK  MEAN   VAR +
1  14  27   14   142.  18.3   4.6 +
2   9  28   20   138.  16.1   9.7 +
3  11  28   18    87.  17.1   8.3 +
4   3  14   12   118.   6.8   4.5 +
TRAINING AREA=   597. PIXELS      +
ALARMED AREA=197745 PIXELS( 75.4%)+
TYPE: CHANNEL #  OR E(X)IT
```

SAN NICOLAS TEST SITE - 21 JUNE 1973

Figure 11. 1-D HISTOGRAMS FROM IMAGE 100 ANALYSIS OF DIGITAL DATA

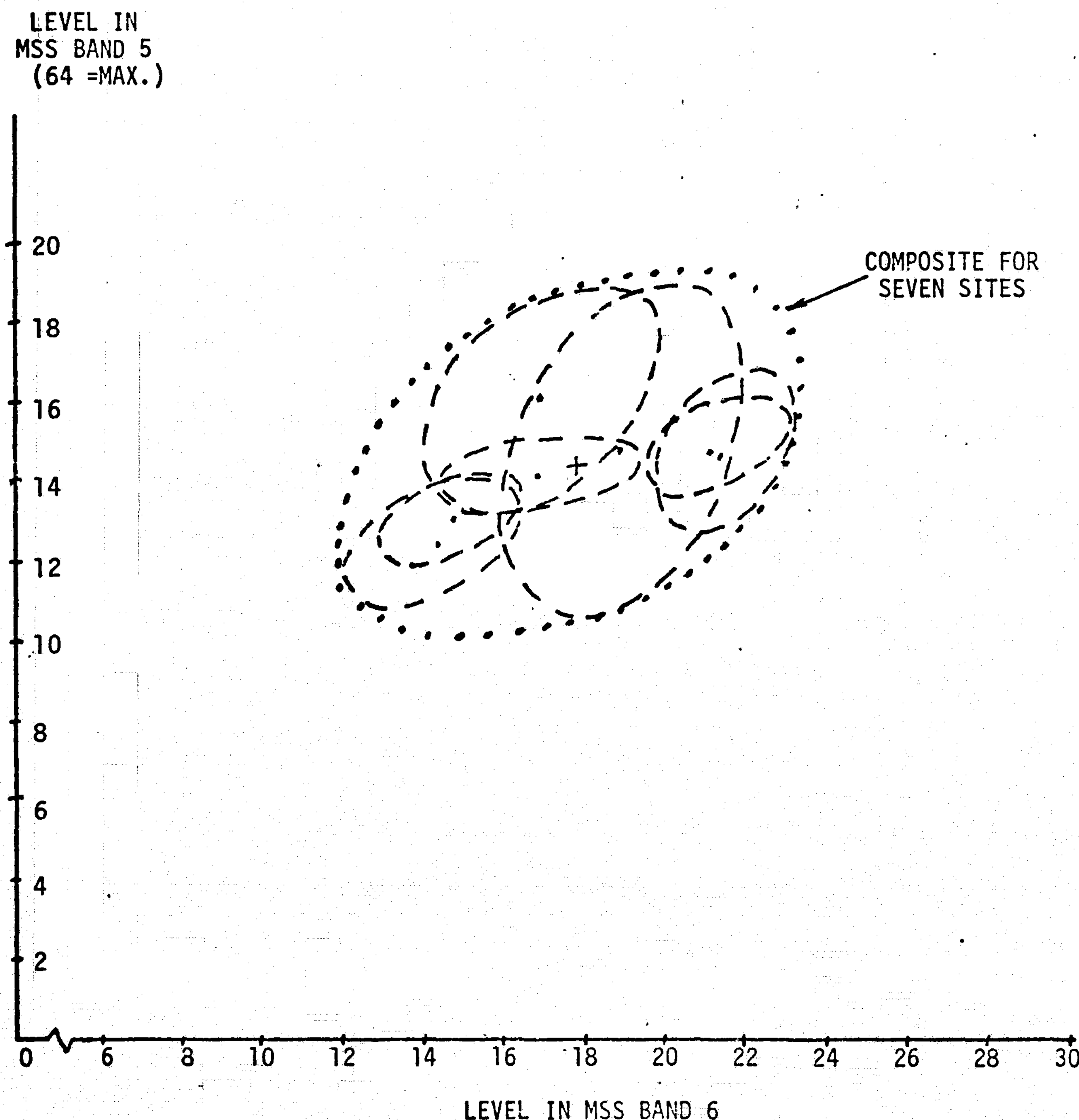


TWO-BAND SIGNATURE MEAN VALUE PLOTS FOR TEST SITES AND OTHER TRAINING AREAS

TWO LOCATIONS (GAPAN, ANGAT) AND FOUR DATES (OCT.,DEC.,JAN.,JUNE)

Figure 12

Using those mean and variance values for MSS bands 5 and 6, and assuming the distribution in 2-space is roughly elliptical, the 2-band signature distributions for the seven sites are sketched in Figure 13. The extracted signature for each of the seven sites for the 21 June 1973 data is shown in 2-space as a mean value point plus the estimated one-sigma boundary in the distribution of all site pixels. If one then wishes to consider the distribution in 2-space of the signature data for all seven sites taken together, a mean value and estimated one-sigma boundary for the composite data may be approximated as shown in the figure.



TWO-BAND SIGNATURES FOR SEVEN GAPAN AREA TEST SITES - JUNE 21, 1973
(MEAN-VALUE PLUS ONE-SIGMA BOUNDARY)

Figure 13

VII. RESULTS ON RICE GROWTH

A. Results Using Human Analysis of Imagery

1. Human, Unaided
2. Human, Zoom Transferscope
3. Human, I^2S Scanner
4. Human, Diazo Transparencies

B. Results Using GEMS (Man + Machine)

For those portions of the investigation requiring heavy machine processing and analysis of data, coupled with human judgment, the GEMS and Image 100 systems were employed. It has been the feeling of the investigators that while considerable analysis was performed and some useful results obtained via GEMS, the overall problem being attacked will yield more fruitful results via Image 100 or a similar system. That is, an all digital man-machine interactive system using LANDSAT digital data appears to be the most likely candidate to provide the capability needed to meet most of the present and future technical and cost effectiveness requirements. For this reason, only the highlights of the results using GEMS to analyze color composite transparencies will be presented here.

In Figure 14 are shown plots of test site mean radiation vs. time in each of the four MSS spectral bands. The data was extracted from black and white single band transparencies. GEMS first was calibrated radiometrically using the step wedge in each transparency. Then, one-dimensional histogram signatures were obtained for each site with the aid of the stored binary electronic site map. The mean value points were read from the histograms and were plotted using the calibration curve, in terms of the steps in the gray wedge. Measurements were made on imagery for four dates: 31 October, 18 November and 23 December 1972; and 28 January 1973. However, not all site/date/band combinations were measured.

Overall, these plots exhibit variations with time in a manner which would be expected when ground truth information is taken into consideration. The minimum radiation is noted at December 23 when most sites are in a flooded stage and transplanting has only recently taken place. There is a rise in the reflected radiation from 23 December to 28 January as rice plant growth begins and the water in the fields becomes a less dominant factor in the reflected site radiation. The Mahipon site is the only one deviating from this situation. It is a rain-fed barrio and thus no flooding or rice growth takes place during the December-January dry season period, although there may well be some weed growth. Looking at Mahipon, Figure 14, in band 7, it is noted that its radiation is higher than all others in December and is one of the lowest in January. This is consistent with the aforementioned conditions. Two further observations may be made. First, one can speculate, although the data sets are incomplete, that most of the information is contained in two bands -- 5 and 7. (Band 6 may be analogous to 7, but insufficient measurements were made for such a conclusion here). Second, the differences in any band among the plots of mean site radiation vs. time are quite small.

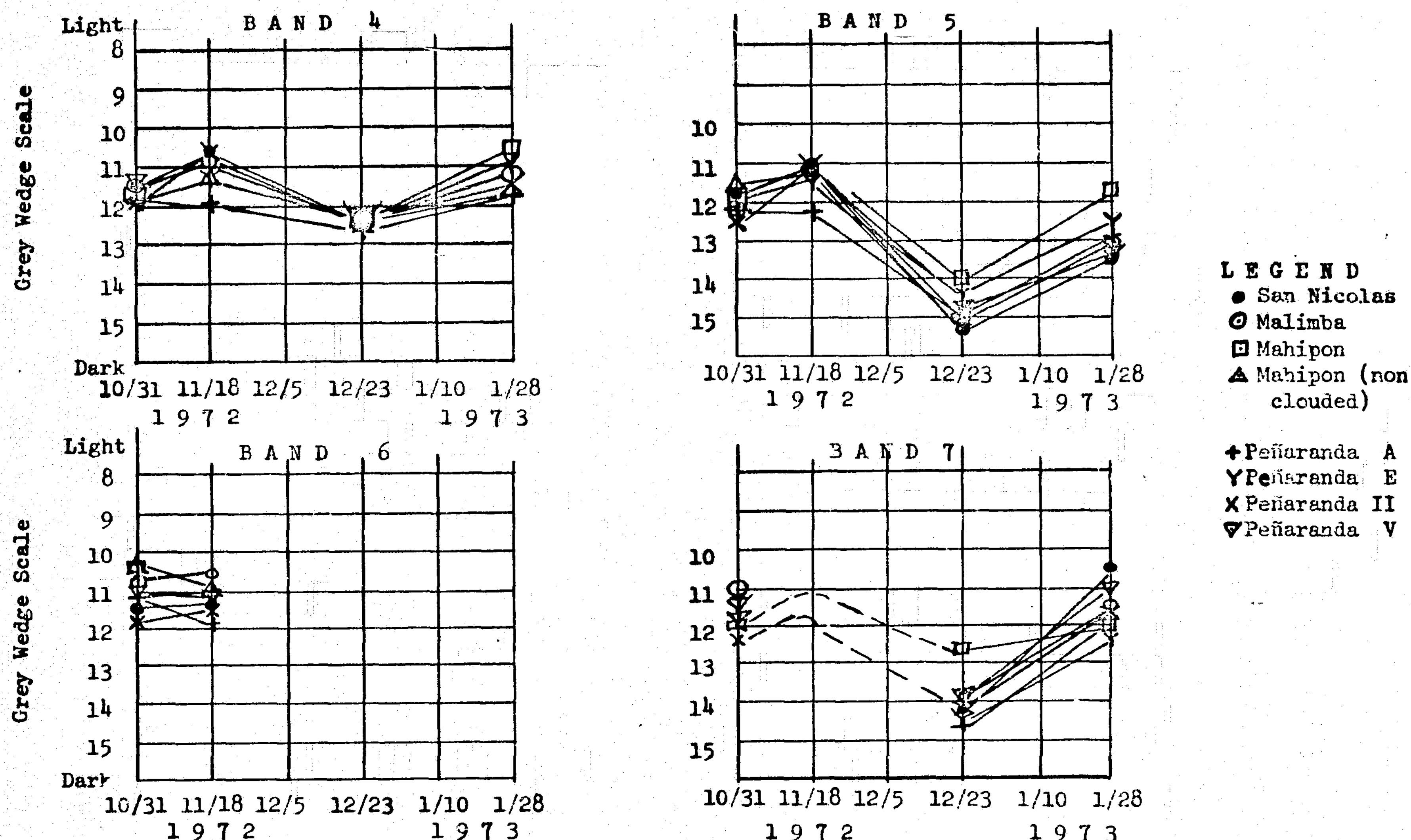


Figure 14. Mean Site Radiation vs. Time

This suggests that, if there are slightly different conditions from site to site at any given time, the signature extraction process is going to have to be well calibrated and accurate and probably involve more sophistication than that employed in this case if the differences are to be detected with confidence. To detect the rice cycle of preparation-planting-growth-harvest, however, should be possible with the type of data shown, although there are questions of spatial resolution to which it is applicable.

The process of determining the mix of features or conditions with a test site, using extracted signatures, has been illustrated previously (see Figure 7). This process was applied to seven test sites in the Gapan area for two or three dates spanning the wet season harvest and the site preparation and early growth for the dry season. Results are shown in Figures 15 and 16. Extracted three dimensional histogram signatures were used in the analysis. In a few instances, as a check on the procedure, the extracted signatures were found to be reasonably repeatable from one analysis date to another.

Referring to the San Nicolas site data in Figure 15, the extracted site conditions appear to be consistent with ground truth. On 31 October (harvest complete) one would expect there to be little evidence of site pixels falling into the color cells corresponding to the reds and pink. Site preparation is in process on 18 November, and the site pixels fall solely in the blue region of 3-D color space - indicating standing water or moist bare soil (more moist than on 31 October). By 23 December there is some early vegetation for the dry season crop. For this date the extracted site conditions begin to exhibit some red along with the dark blue and bluish pink - evidence of some vegetation along with standing water.

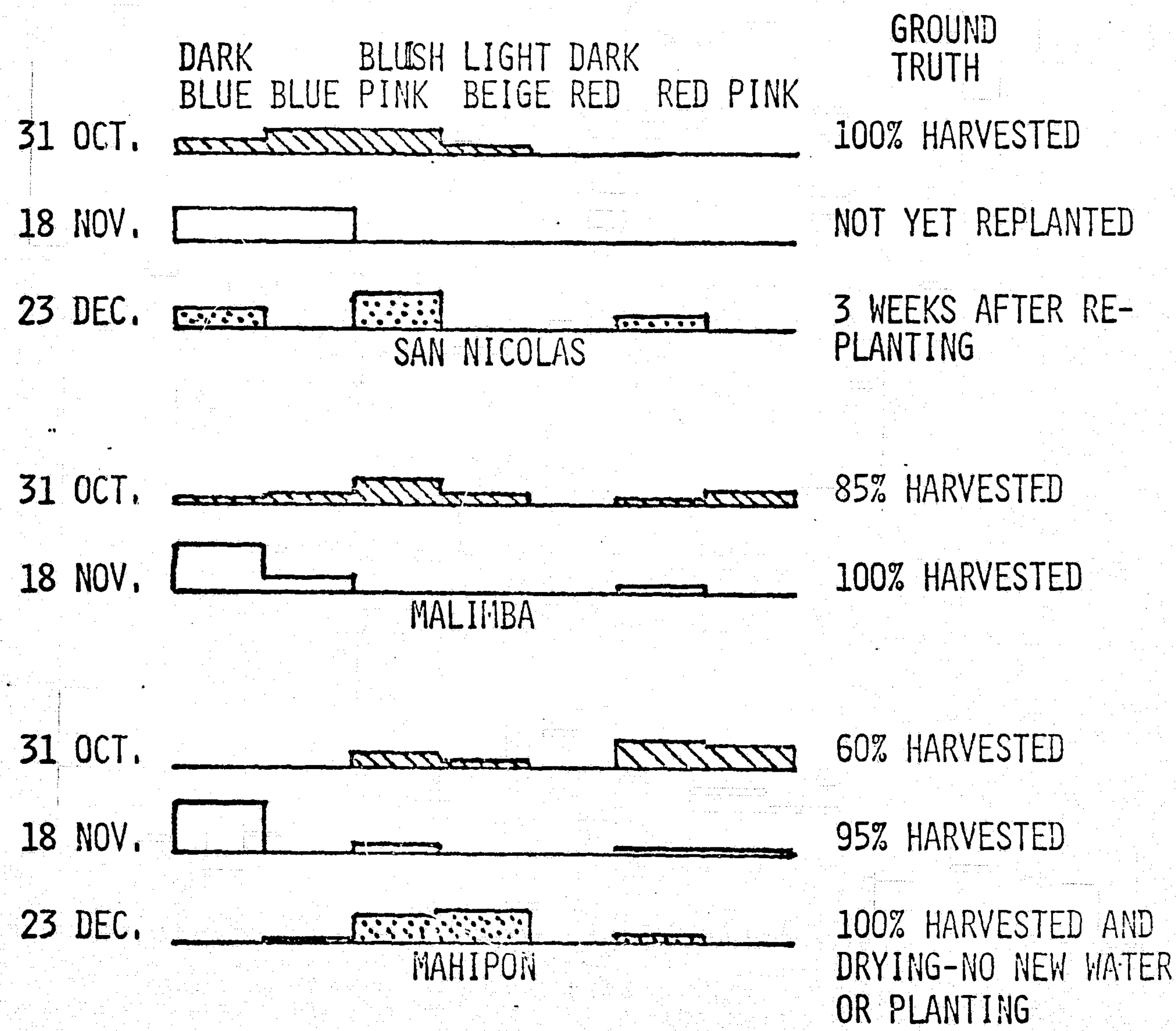
The Mahipon site shown in Figure 15 still had about 40% standing rice on 31 October. The extracted site conditions generally support this situation, although there is a slightly higher proportion of site pixels in the red and pink than the standing rice percentage would suggest. When the site is 95% harvested by 18 November, the percent pixels falling into red and pink has now dropped to reflect this. On 23 December one can expect no standing water, but bare drying soil with some small evidence of weedy vegetation. Mahipon is rain fed only, and no rice crop was planted during this dry season period. Site pixels from the extracted signature fall into color regions of color space which are consistent with such conditions.

Similar correspondence of extracted site conditions with ground truth may be noted for all other sites in Figures 15 and 16. In all cases the qualitative correlations with ground truth, and the temporal trends, are quite good. But, the quantitive site feature mix does not always match the quantitative ground truth.

C. Results Using IMAGE-100 (Man + Machine)

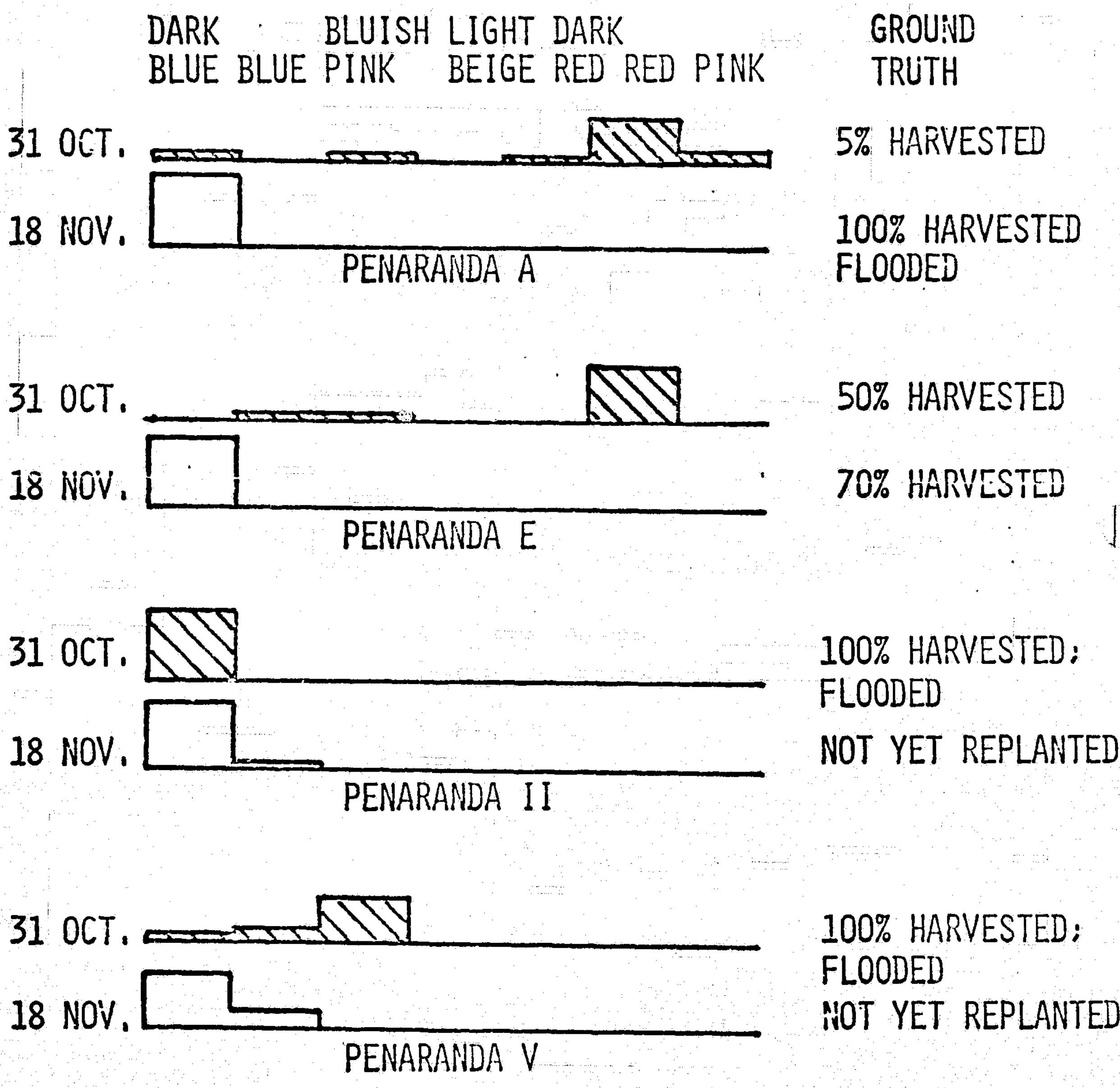
All Image 100 analysis results presented in this section were obtained using LANDSAT 1 digital MSS data.

Using the procedure described previously, the mean site radiation was extracted from the image data for all combinations of seven sites, four MSS spectral bands and four dates: 31 October and 23 December 1972



EXTRACTED SITE FEATURE MIX USING GEMS
AND COLOR COMPOSITE TRANSPARENCIES

Figure 15



EXTRACTED SITE FEATURE MIX USING GEMS
AND COLOR COMPOSITE TRANSPARENCIES

Figure 16

and 28 January and 21 June 1973. Results for two of the sites and three of these dates* are shown in Figure 17, along with corresponding measurements made months earlier using GEMS and color composite transparencies. (Using a calibration curve relating step number in the color composite step wedge to quantized signal gray level value in the digital data, the GEMS results were converted to equivalent digital signal levels).

Examining the course of the Image 100 derived site mean value plots vs. time, it can be observed that the temporal trends are consistent with ground truth. Specifically, one can note the intensity minima in MSS bands 6 and 7 on December 23 — a time when irrigated sites are flooded and which is near the transplanting date. Rice plant early growth occurs between the 23 December and 28 January dates, and the rise in signal intensity in MSS bands 6 and 7 is apparent. Note that the rise is greater for Penaranda Site V than for Site E. This is consistent with the three weeks of additional growth from the transplanting date for Site V. It can be observed also that, during the plant growth in the 23 December - 28 January interval, the signal intensities in MSS band 5 decrease -- with a greater decrease for the site where there has been more weeks of growth since the transplanting date. This trend, again, is expected.

Finally, in connection with the site mean gray-level plots vs. time as shown in Figure 17, a comparison is in order for results via GEMS and color composites vs. results via Image 100 and digital data. There was no Image 100 analysis of data for the 18 November date as there had been using GEMS. Therefore, it is not feasible to compare the plots from the two sources for that date. Plot correlations in MSS band 4 are fair, but there is a lesser interest in band 4 for the present application. Because of incomplete GEMS data, comparisons in band 6 are limited. For the two remaining bands, the following comparisons are immediately apparent:

a) In band 7, the temporal trends are similar for the data from both sources, with the GEMS color composite source producing the greater magnitude of data temporal change.

b) In band 5, the correlation of temporal plots from the two sources is very good for the 31 October and 28 January dates. But the GEMS color composite source produced results for 23 December which deviate considerably from results via Image 100 - digital data. The GEMS derived mean site radiation values for this date are very low.

While there could be several factors accounting for the differences, we have not been able to pinpoint the specific reason(s). It can be said that the deviations for other site plots not shown in Figure 17 were all very similar in nature to those shown in the figure. One is tempted to assume, therefore, that there are certain inherent limitations in extracting accurate radiometric (gray-level) data from transparencies using GEMS, or that there may be gray-level limitations

*Results for other sites are similar and, although not shown here, are a part of the two band extracted signature results plotted in subsequent figures. The mean values for June 1973 are omitted since there are no GEMS results for comparison. The June results appear in subsequent two-band signature plots.

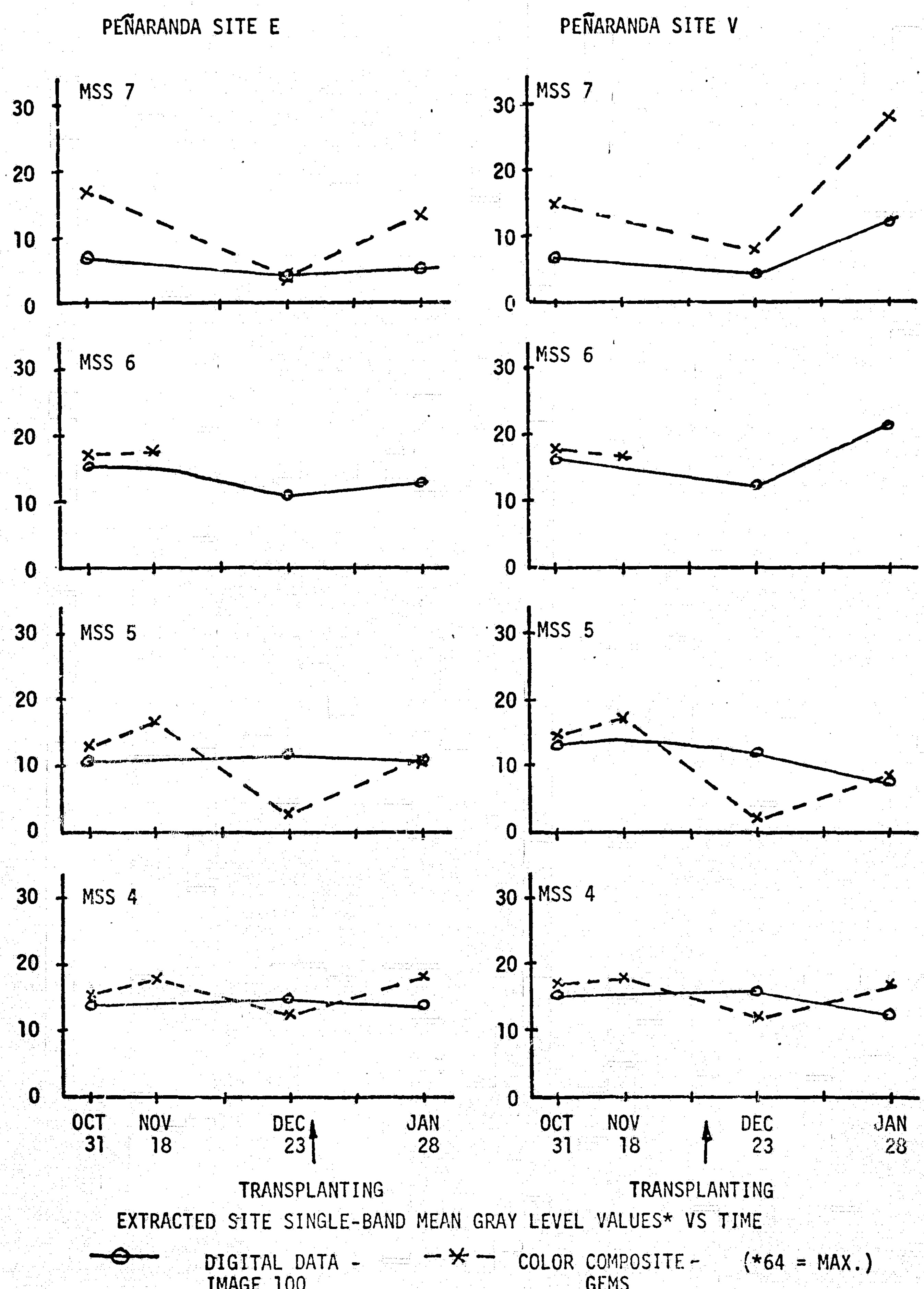


Figure 40. Extracted Site Single-Band Mean Gray Level Values vs. Time

(relative to digital data) in the black and white single-band transparencies themselves. But, these are only hypotheses. We are inclined to rely more heavily, however, on the digital data and its extraction via Image 100 when fine-grain, accurate radiometric data is desired.

Refer now to Figure 18 and the two-band signatures for rice and other features. The signatures plotted (mean value plus estimated one-sigma boundary of the distributions in 2-space) were prepared as described previously using extracted 1-D histogram signatures. The four elliptical signature regions for the rice sites at different times in the overall cycle are each composites of the signatures for several individual sites where conditions are roughly similar. The fact that these elliptical regions are large indicates the diversity of conditions prevailing even after grouping the data for what appeared to be approximately similar conditions. All other signatures shown pertain to single (not necessarily small) training areas in the scene.

Several observations may be made concerning the non-rice signatures:

a) Signatures for tidal flats and for swamp vegetation can serve as a calibration or check on rice signatures - bracketing the range from an area which can look like a prepared site with no vegetation to one with lush vegetation and considerable moisture.

b) At any given time (e.g., December or June) one can find different features in the scene having considerably different signatures.

c) In the rain fed area north of Gapan town (between the rivers) a crop is going through a growth cycle from December to June which differs in its timing and in its two band signatures from those for rice in the nearby irrigation system to the south. The identity of this crop is not known, but according to our ground truth specialist in the Philippines, it is not rice.

d) Signatures for non-rice areas can be similar to signatures for rice fields in some stage of the overall rice growth cycle. For example, note the signatures for mangoes.

Figure 19 is a repeat of Figure 18 with the addition of some dashed lines and small circles indicating what appears to be the signature path vs. time in 2-space for rice sites. This rice temporal signature cycle has to be considered as an estimate only, based on the limited data available from which to derive the pattern. However, it is probably a reasonable approximation when one considers it in relation to the signatures for tidal flats, swamp vegetation and rain-fed areas in the dry season. This rice two-band temporal signature cycle is plotted alone in 2-space in Figure 20. The path is believed to take two different courses from harvest to the subsequent transplanting, depending upon whether the wet or dry season is approaching.

Figure 21 is intended to illustrate that during harvest, rice sites are particularly non-homogeneous. While some fields have just been

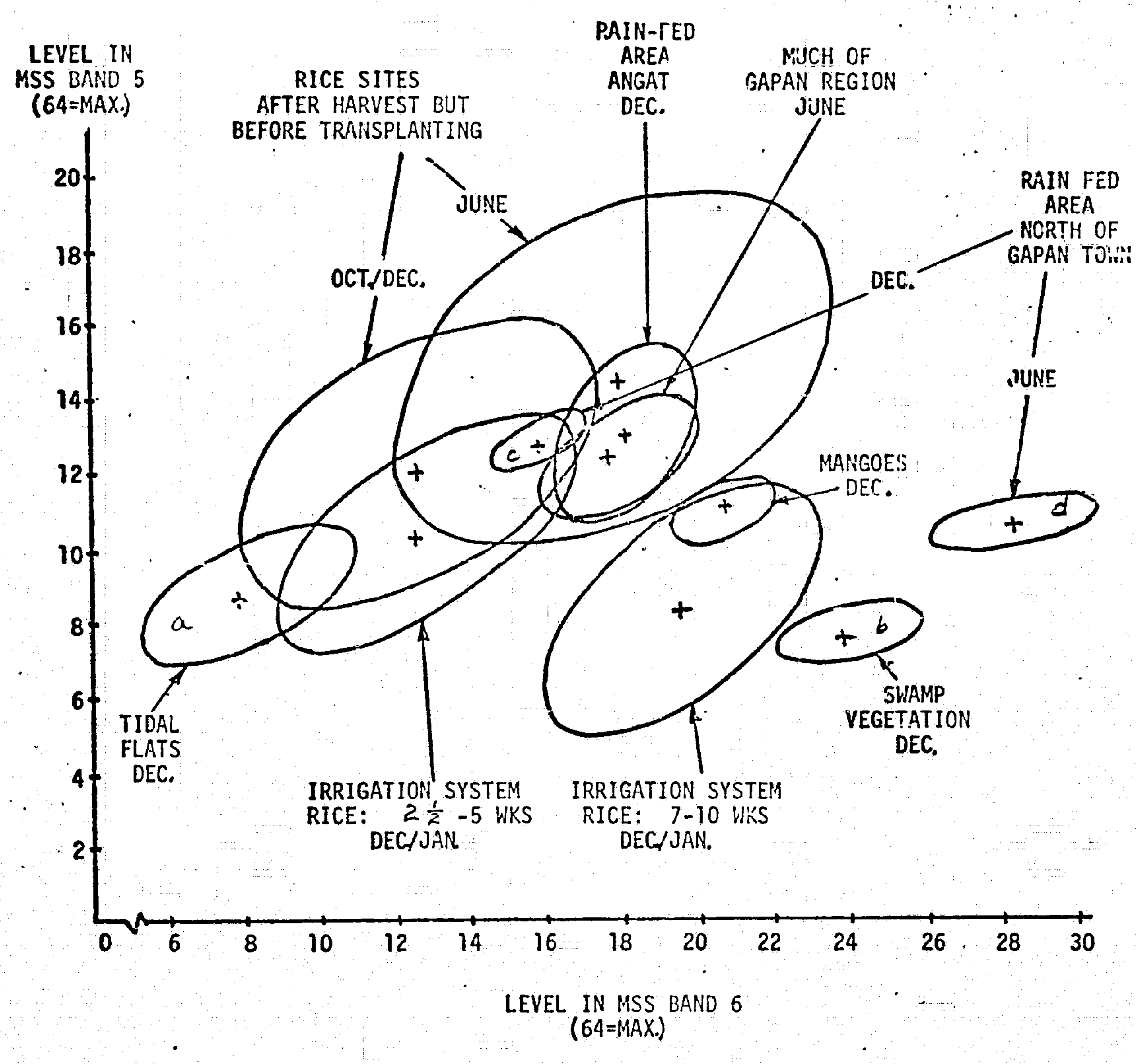


Figure 18. TWO-BAND SIGNATURES FOR RICE AND OTHER FEATURES (MEAN VALUE PLUS ESTIMATED ONE-SIGMA BOUNDARY)

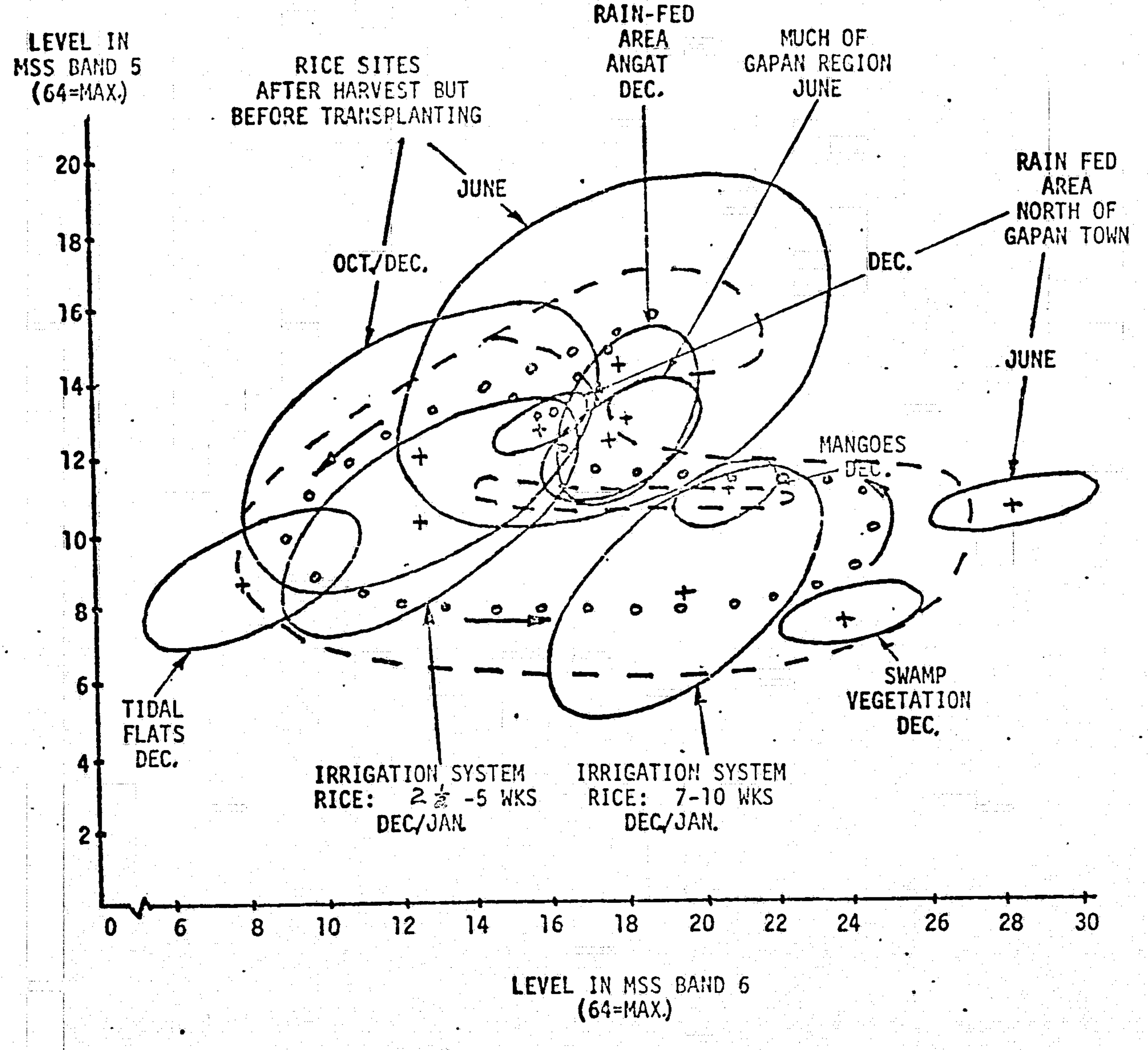


Figure 19: TWO-BAND SIGNATURES FOR RICE AND OTHER FEATURES (MEAN VALUE PLUS ESTIMATED ONE-SIGMA BOUNDARY)

AND

ESTIMATED RICE TEMPORAL CYCLE

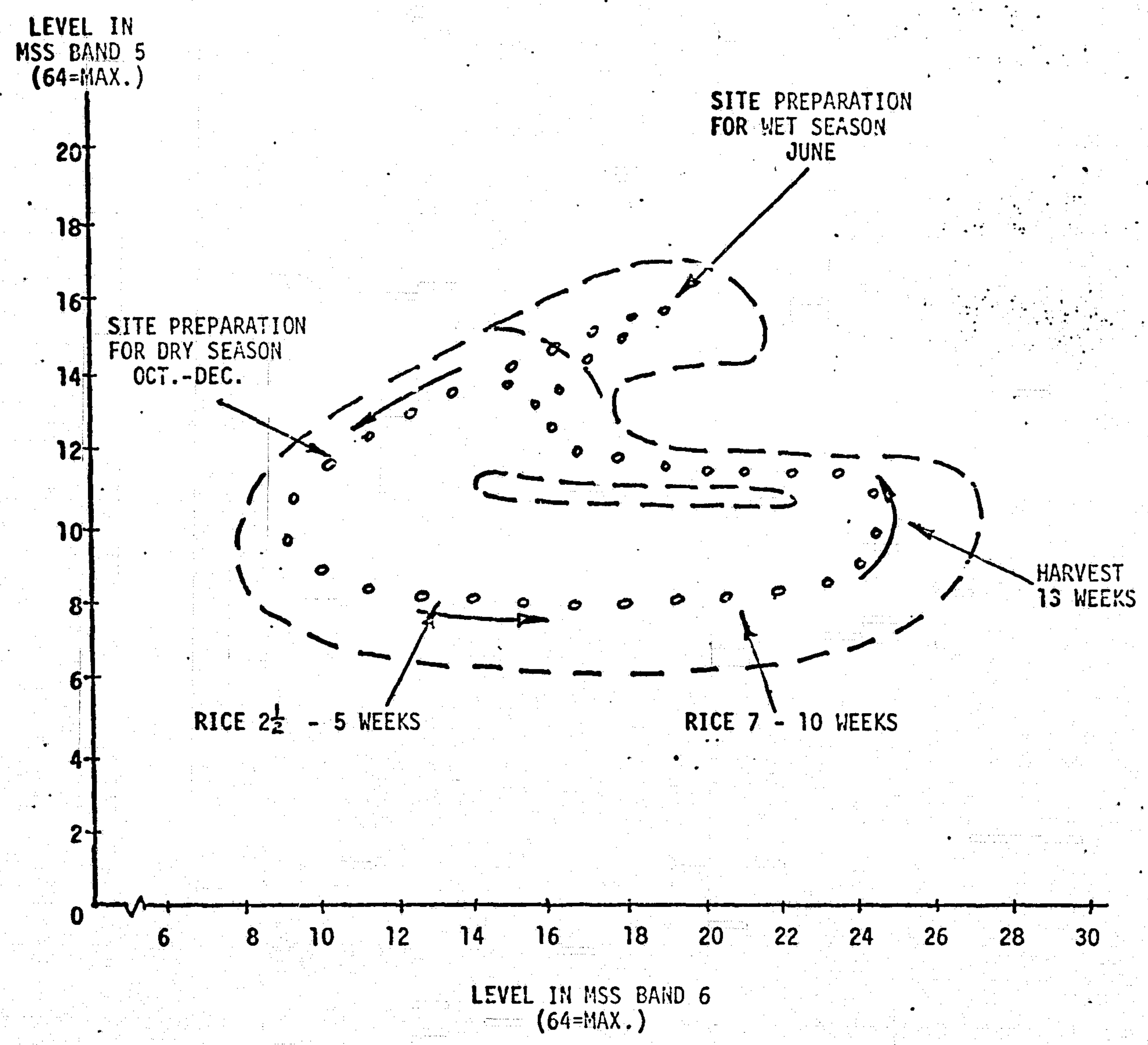
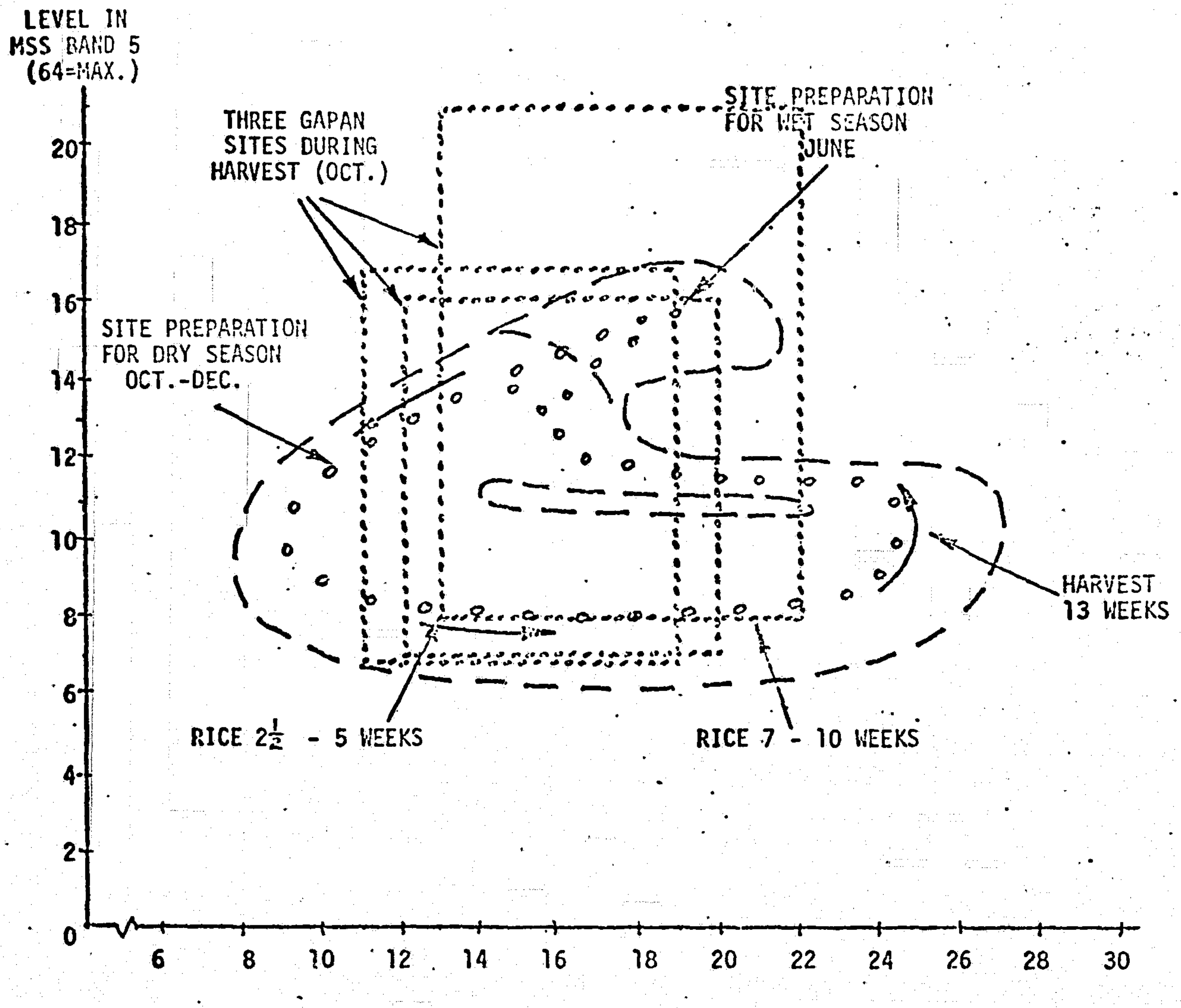


Figure 20. ESTIMATED TWO-BAND TEMPORAL SIGNATURE CYCLE FOR IRRIGATION SYSTEM RICE

(TWO CROPS PER YEAR)



SIGNATURE BOUNDS FOR THREE GAPAN SITES DURING MID-HARVEST (OCTOBER)
AND
ESTIMATED TWO-BAND TEMPORAL SIGNATURE CYCLE
FOR IRRIGATION SYSTEM RICE

(TWO CROPS PER YEAR)

Figure 21

harvested, others near by may have been harvested two weeks earlier, and still others may have rice still standing. The signatures for three Gapan area sites having such conditions on 31 October 1972 were examined. The maximum and minimum bounds in 2-space for these three signatures are plotted in Figure 21 as rectangles overlaying the estimated rice temporal signature cycle. The large size of these rectangles indicates that at the same time some pixels fall near the site preparation phase of the cycle, some near the post harvest phase and some near the mature standing rice phase.

1. Testing Gapan Site Data on Angat Data

Having arrived at the estimated rice temporal signature cycle using mostly test site data for the Gapan region, some signature testing and classification was performed in a different region--that in the vicinity of the Angat River Irrigation System. First, it should be stated that because of a lack of time, test sites in the scene were not located to the extent of preparing a stored electronic site map as was done for Gapan. Professor Senen Miranda of the Univeristy of the Philippines, Los Banos was a participant at the console in the Image 100 analyses, however, and determined a few key site locations through interpretation of the system display of the scene. Specifically, with Professor Miranda's guidance, the system was caused to train (extract signatures) in four representative areas of the scene for 23 December 1972: 1) Rice one month after transplanting; 2) more mature rice; 3) a tidal flat area; and 4) a rain-fed area outside the irrigation system. The signature bounds in 2-space for these training areas are shown in Figure 22, superposed on the previously established estimated rice temporal signature cycle. It will be noted that the four signature regions fall into apparently proper positions in the temporal cycle.

The results of the classification for this selected portion of the Angat region are shown in Figure 23. This figure is actually a composite prepared from four individual theme "maps" printed out by Image 100. For reference purposes the classification map has been annotated to show some of the key rivers and irrigation laterals. In particular, the waterway at the eastern (right hand) edge of the irrigation system is shown, and it may be seen that the classification shows essentially a rain-fed, currently dry, area to the right of this. The field of view here is approximately 30 km x 26.7 km or 18 miles x 16 miles. The other classified areas of the scene conform to ground truth as nearly as could be ascertained by Professor Miranda.

2. Analyses of Spectral/Temproal Image Data

We come now to results of sets of analyses based on the use of spectral/temporal image data. It was noted previously that, at least in the environment of that portion of the Philippines we have studied, it is possible to find at any time of the year near-by land features exhibiting an extreme variety of conditions and signatures (e.g., lush vegetation; bare, moist soil; dry, weedy soil; etc.) Further, many of these features can have signatures which are similar to those for rice fields during some portion of the overall rice site cycle. While it still may be possible to rely mostly on spectral signatures to achieve the long-range objectives identified in this investigation (particularly

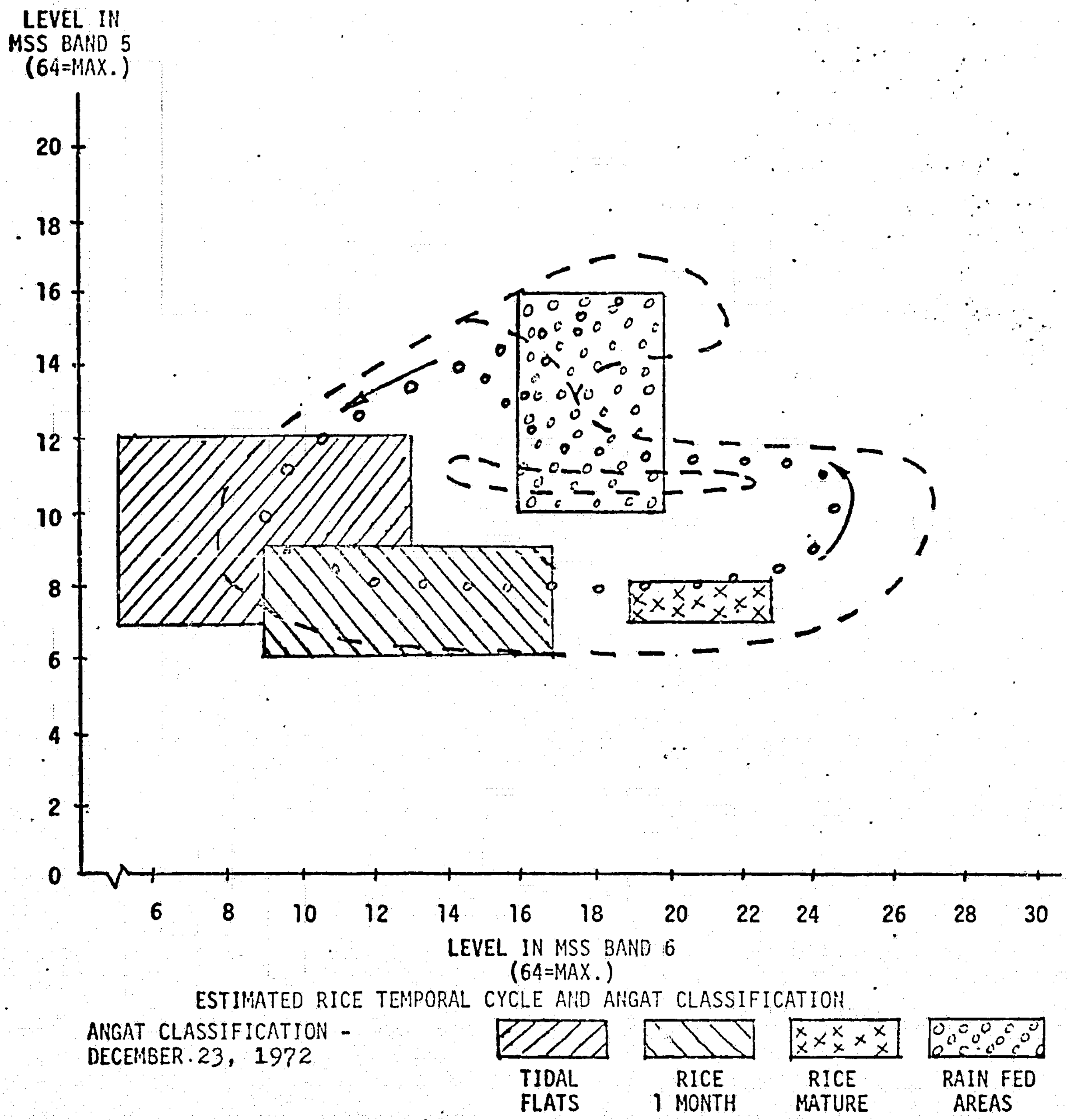
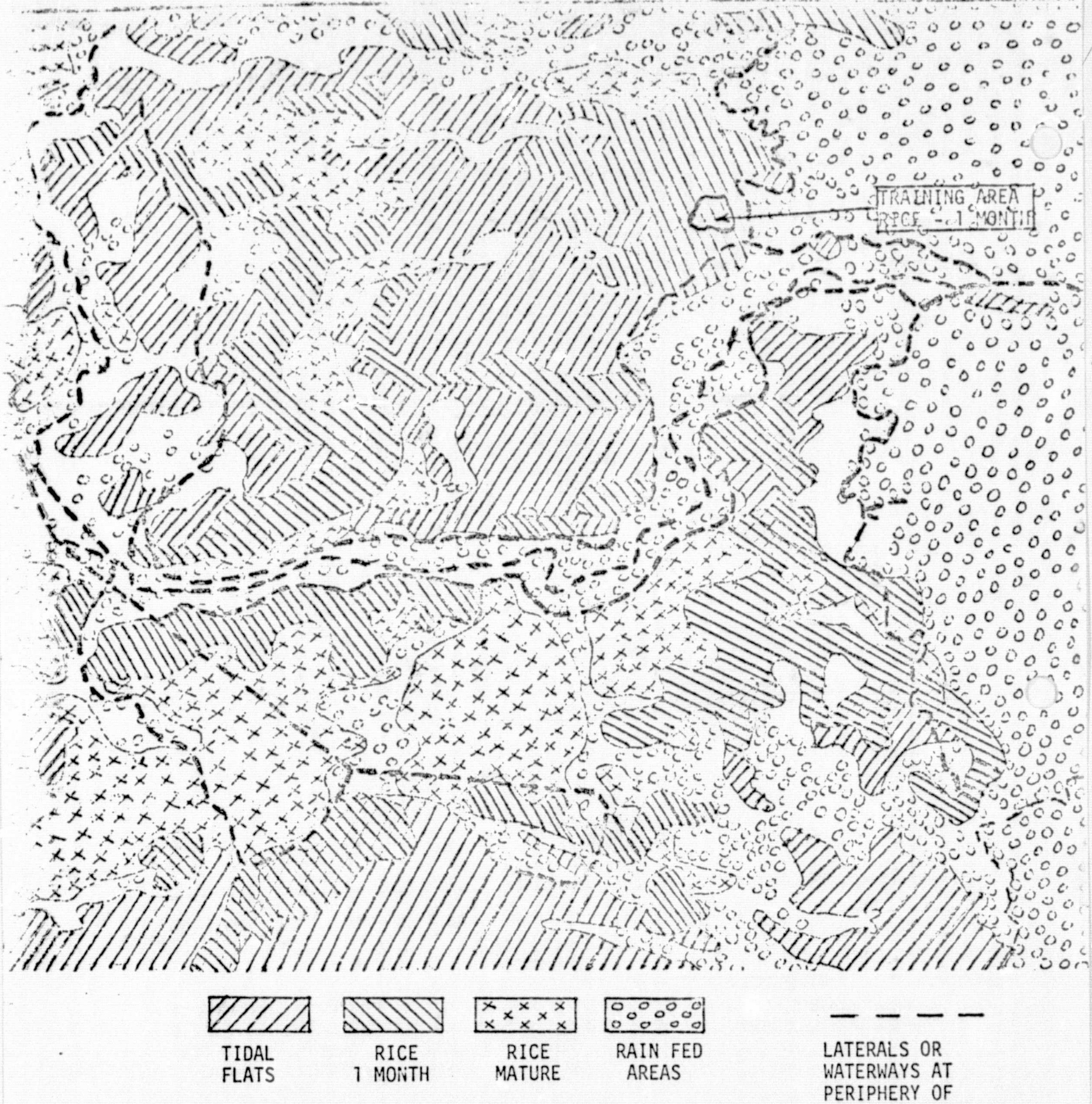

LEVEL IN
MSS BAND 5
(64=MAX.)
20
18
16
14
12
10
8
6
4
2
0
6
8
10
12
14
16
18
20
22
24
26
28
30
LEVEL IN MSS BAND 6
(64=MAX.)
ESTIMATED RICE TEMPORAL CYCLE AND ANGAT CLASSIFICATION
ANGAT CLASSIFICATION -
DECEMBER 23, 1972
TIDAL
FLATS
RICE
1 MONTH
RICE
MATURE
RAIN FED
AREAS

Figure 22



ANGAT REGION
MULTISPECTRAL CLASSIFICATION USING ERTS DATA FOR DECEMBER 23, 1972
DRY SEASON

Figure 23

if the two-step recognition process is employed), it was felt desirable to examine some of the potential of spectral-temporal signatures as a means to minimize possible confusion due to overlapping spectral signatures in the classification process. The approach taken was a good choice at the time and does indicate the potential of the method, but more effective procedures would likely be employed in future analyses.

The four-band digital MSS data for the Gapan scene (30km x 30km or 18 miles x 18 miles field-of-view, 512 x 370 Landsat pixels) were assembled in files on tape for four Landsat 1 overflight dates: 31 October 1972, 23 December 1972, 28 January 1973, and 21 June 1973. After registering the four files, a new multi-channel scene file was prepared consisting of:

Channel 1 - MSS Band 6 for October

Channel 2 - MSS Band 6 for December

Channel 3 - MSS Band 6 for January

Channel 4 - MSS Band 6 for June

This new file was read in to Image 100 and analyzed using procedures which treated the single band, multi date data essentially as if it were multi band, single-data data (as used in analyses described to this point).

The registration procedure was not ideal and would be superseded in future analyses by more sophisticated capabilities now available. For the results reported here, however, the registration was accomplished simply by a translation in X and Y under the control of the analyst for three of the multispectral data files relative to the fourth--the file for 23 December 1972. Viewing a display of composite data, the analyst made judgments as to when "best" registration occurred. To aid the analyst, the procedure involved display of the theme of river reference marks (prepared from the 23 December data) superposed on the full-color multispectral display of the scene for the file (one of the other dates) being registered. This procedure, although cumbersome, worked well except for the limitation that no data rotation capability was available at the time. Registration was good near the test sites at the center of the field of view, but was in error two or three pixels at the corners of the scene. Rotation error relative to the December file was off in one direction for October and in the opposite direction for June. The need for different rotation corrections is assumed to be due to changes in the satellite orbit during the eight month interval from October to June. Net registration errors in the vicinity of the test sites was considered to be one or two pixels.

Several analysis approaches were available for the spectral temporal data:

a) Perform 1-D training (as if the data were single-date, multispectral), and alarm all scene pixels having similar signatures.

b) Supplement (a) with 1-D histogram signature limit modifications using analyst judgment while viewing the histograms and the alarmed scene.

c) From previous multispectral signature analyses, predict the desired MSS band 6 signatures for the four dates for rice and other scene features, and set these signatures into Image 100 so as to produce a scene alarm based on them.

Actually, all three procedures were used and a number of temporal signatures and classifications were obtained. The signatures for five of the spectral/temporal classification themes (A, B, C, D, E) are presented in Figures 24 and 25, which show also many of the previously extracted two-band, single-date signatures and the estimated rice temporal signature cycle. Bar length for the temporal theme signature corresponds to the band 6 gray level pass (recognition) range for file data of the date indicated. Themes A, B and C result from two-date signatures, while Themes D and E are produced by four-date signatures.

Figures 26 and 27 show, respectively, the classification themes using spectral/temporal signatures for late- and early-planted rice. The signatures for these two themes were established from spectral signature data extracted previously for several test sites. The signatures were predicted and not modified during classification. Very likely, they are not optimum, and should be adjusted in an iterative procedure involving further correlation with ground truth where such is available. Note that the theme for late-planted rice (2.5 - 5 weeks growth on 29 January) includes most of the Peñaranda A and E test sites at the upper right of the site group. This is consistent with ground truth data for those sites. The theme for the early-planted rice (7 - 10 weeks growth on 29 January) includes most of the San Nicolas test site (upper left in the site group). This, too, conforms to ground truth. The Mahipon site at the far right was not planted to rice during this season and properly does not appear in either theme. Ground truth indicates an early planting for rice in the Malimba site (lower left in the site group), but neither early- or late-planting themes fall heavily in Malimba. It is suspected that the planting for Malimba fell midway between the "early planting" and "late planting" conditions we had established so that another spectral/temporal signature would have been needed to recognize the rice status at Malimba. Evaluation of the themes at the Peñaranda C, II and V sites is omitted since these sites are small, and small errors in site location could materially affect the evaluation results.

The spectral/temporal classification theme for the irrigation system benefited area is shown in Figure 28. The signature for this theme is such that the theme will include (1) areas which are essentially flooded fields in December but which exhibit a small degree of vegetation in January, and (2) areas which in December are flooded but contain some vegetation, then exhibit more vegetation in January. It can be seen that all of the test sites except Mahipon (not planted) are included in the theme. This conforms to ground truth. For this theme, the spectral/temporal signature was predicted from previously extracted spectral signature data from several test sites, and then the spectral/

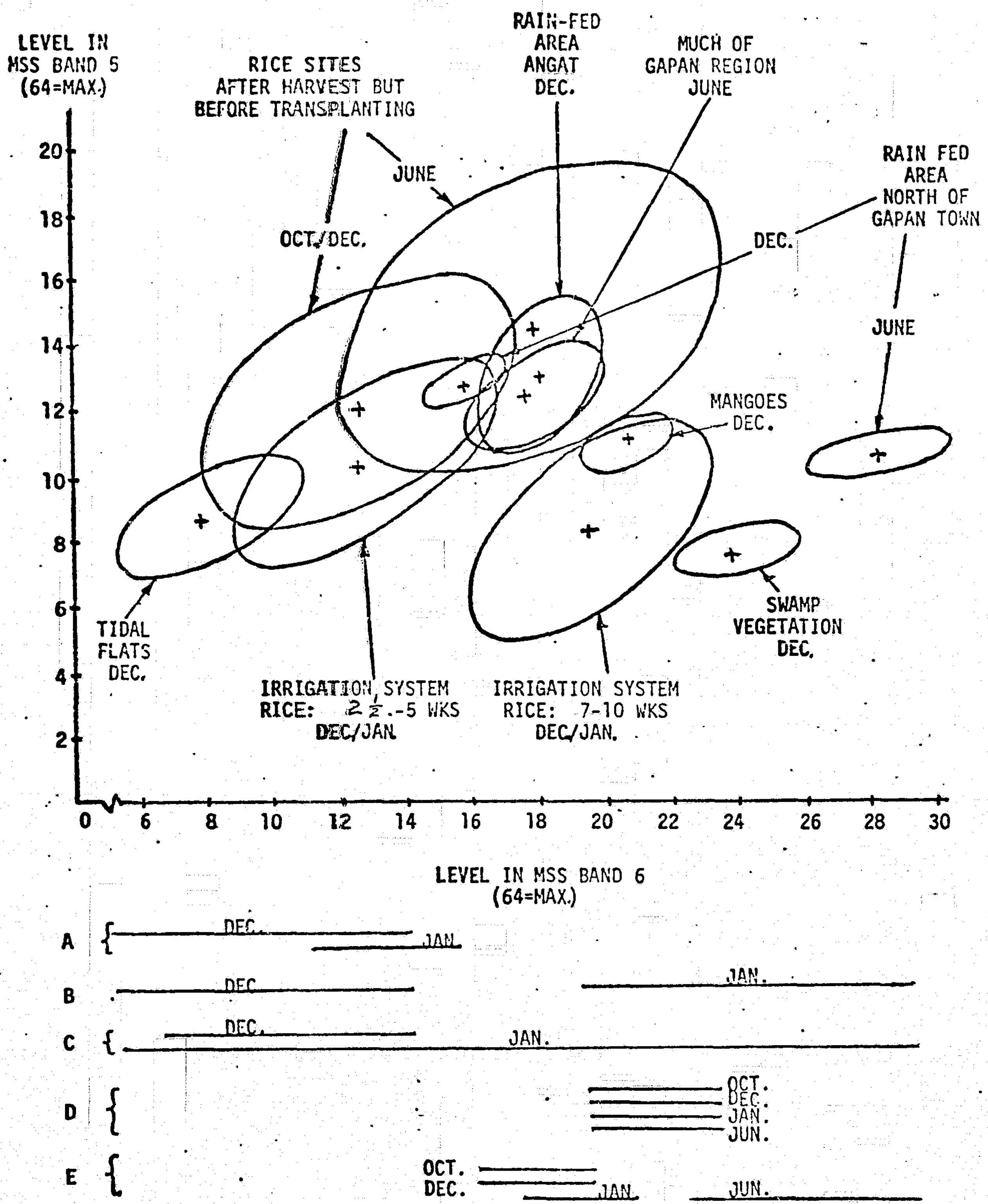


Figure 24. TEMPORAL SIGNATURES AND TWO-BAND SPECTRAL SIGNATURES FOR RICE AND OTHER FEATURES

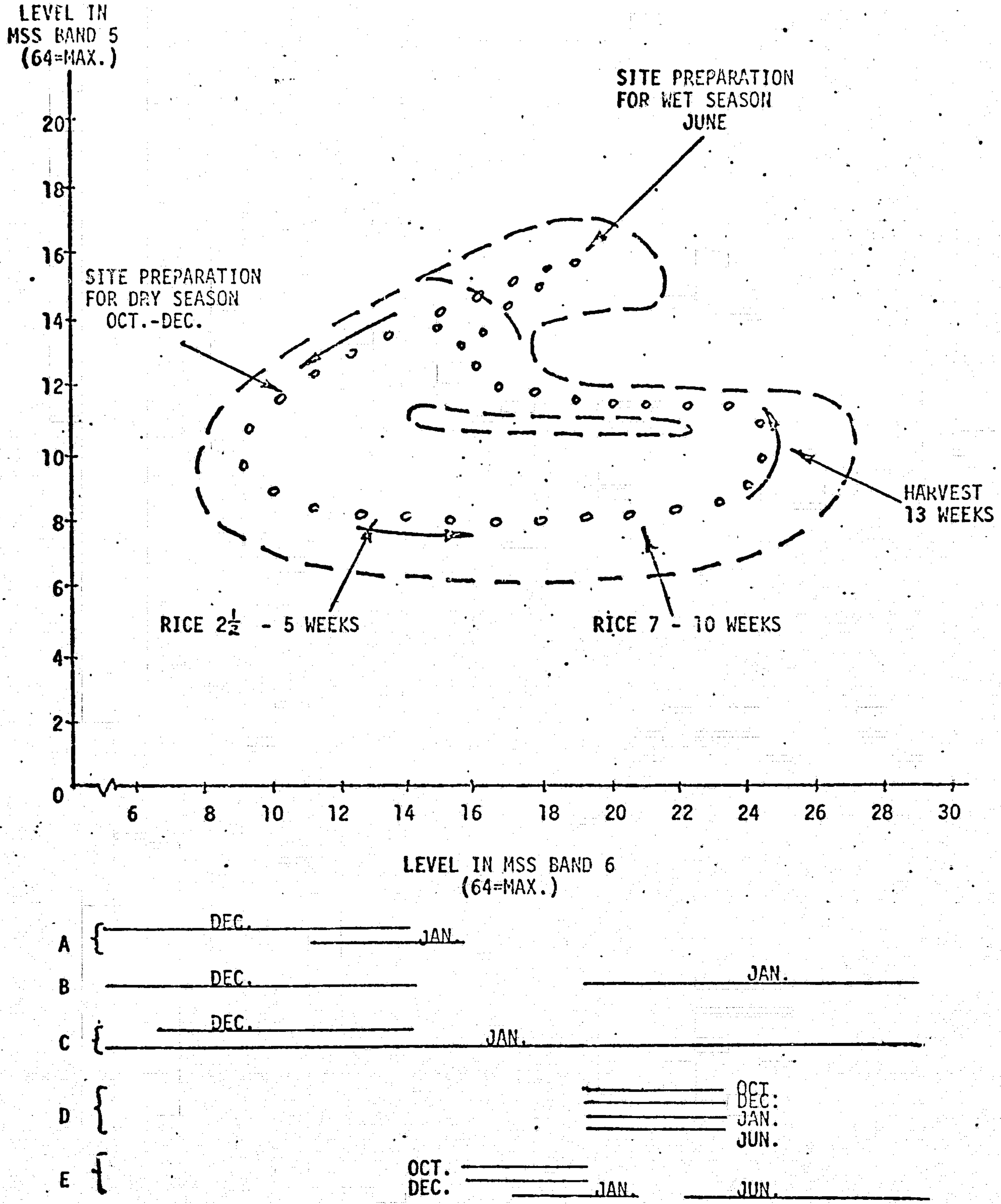


Figure 25. TEMPORAL SIGNATURES AND

TWO-BAND SIGNATURE CYCLE FOR IRRIGATION SYSTEM RICE

THEME A RESULTS FROM A 2-DATE SPECTRAL-TEMPORAL SIGNATURE BASED ON SIGNATURES EXTRACTED FROM TEST SITES FOR 23 DEC 72 AND 29 JAN 73.

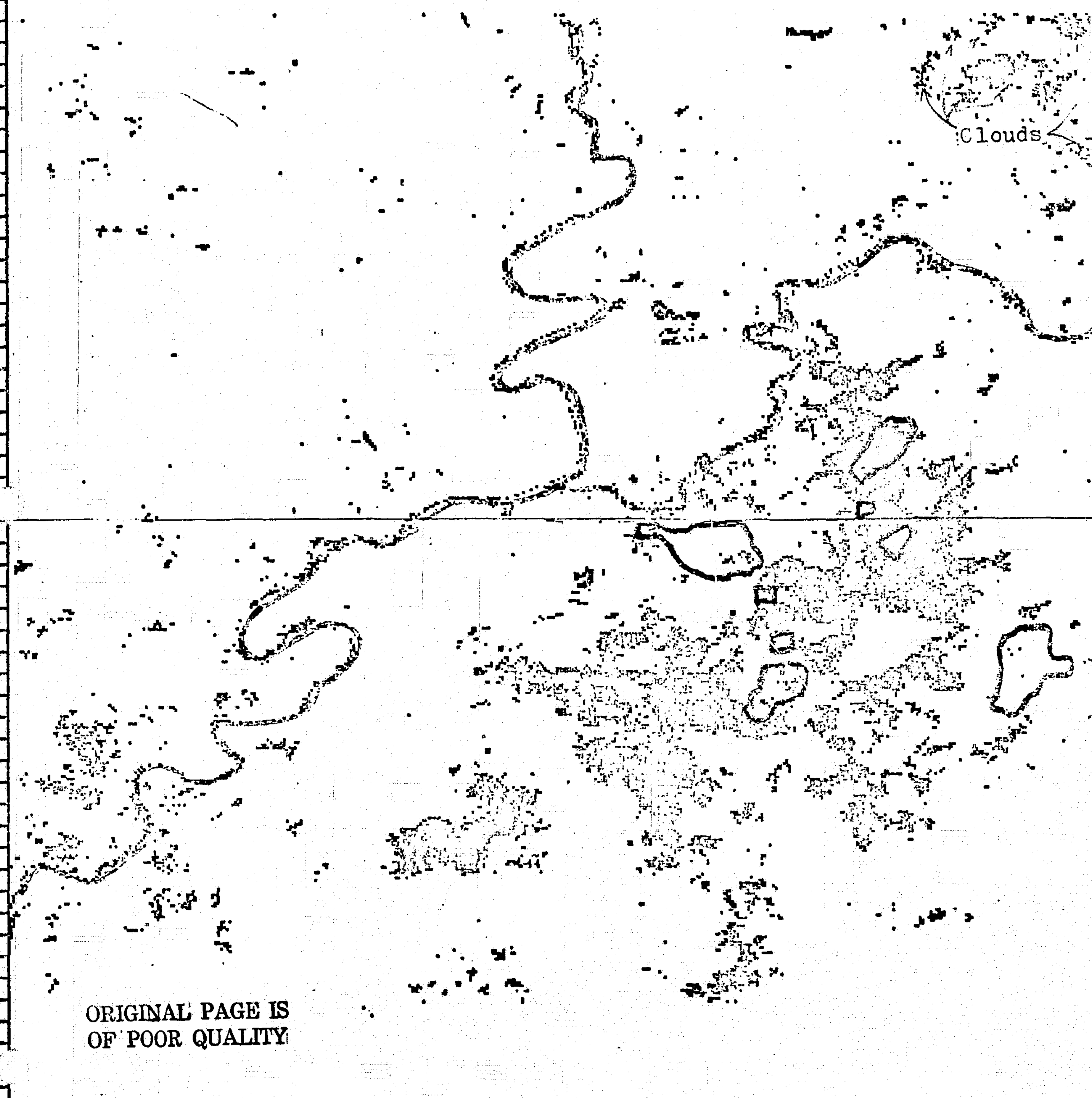


Figure 26. GAPAN REGION TEMPORAL CLASSIFICATION THEME A SHOWING IRRIGATION SYSTEM RICE EXHIBITING 2.5-5 WEEKS GROWTH ON 29 JAN 73

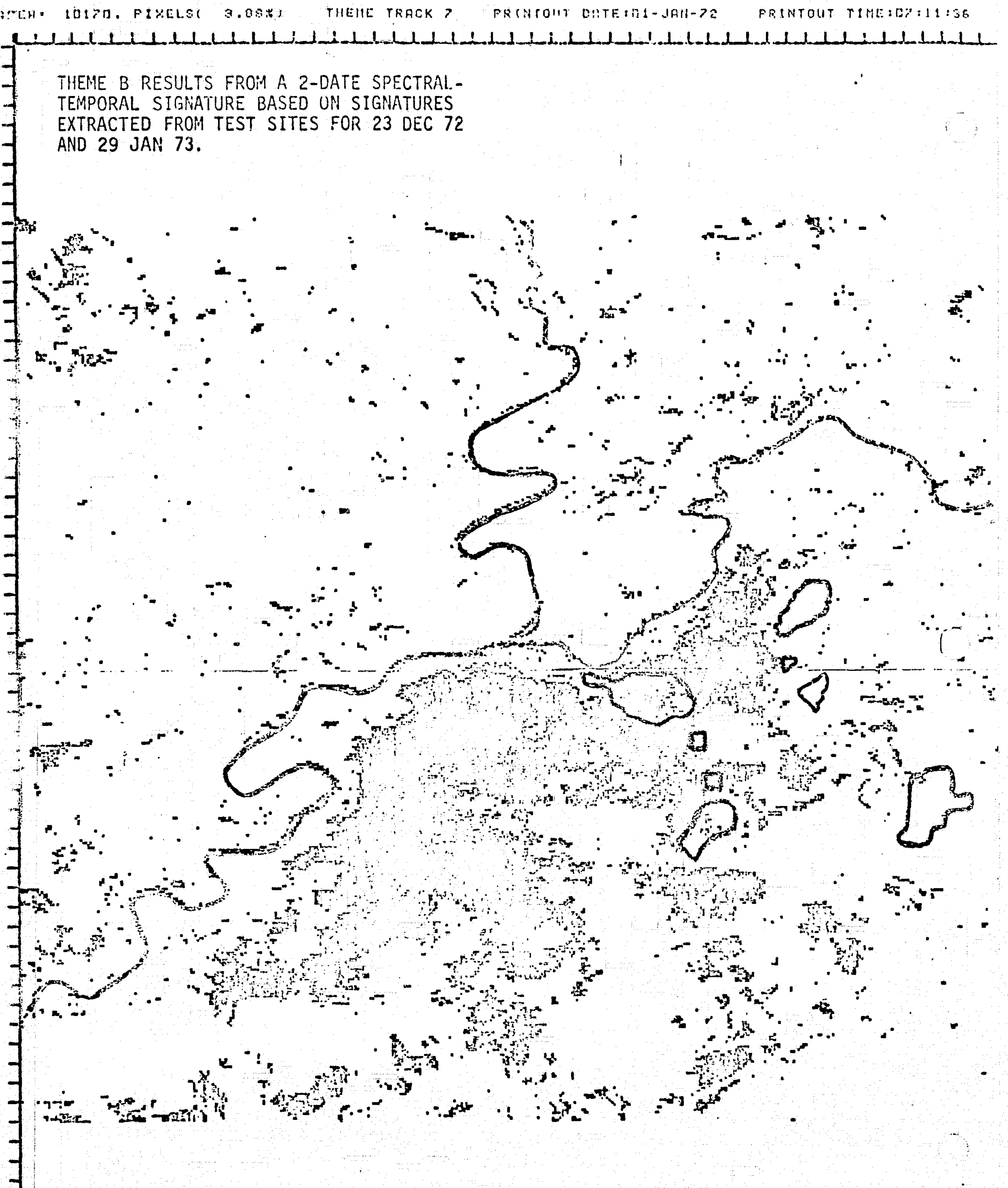


Figure 27. GAPAN REGION TEMPORAL CLASSIFICATION THEME B SHOWING IRRIGATION SYSTEM RICE EXHIBITING 7-10 WEEKS GROWTH ON 29 JAN 73

AREA= 28043. PIXELS(10.7U%) THEME TRACK 1 PRINTOUT DATE:01-JAN-72 PRINTOUT TIME:07:07:05

THEME C RESULTS FROM TRAINING USING 2-DATE SPECTRAL-TEMPORAL IMAGE DATA FOR 23 DEC 72 AND 29 JAN 73. DECISION BOUNDARIES IN SPECTRAL SPACE WERE THEN MODIFIED UNTIL THE ALARMED AREA IN THE SCENE CORRELATED SATISFACTORILY WITH GROUND TRUTH.

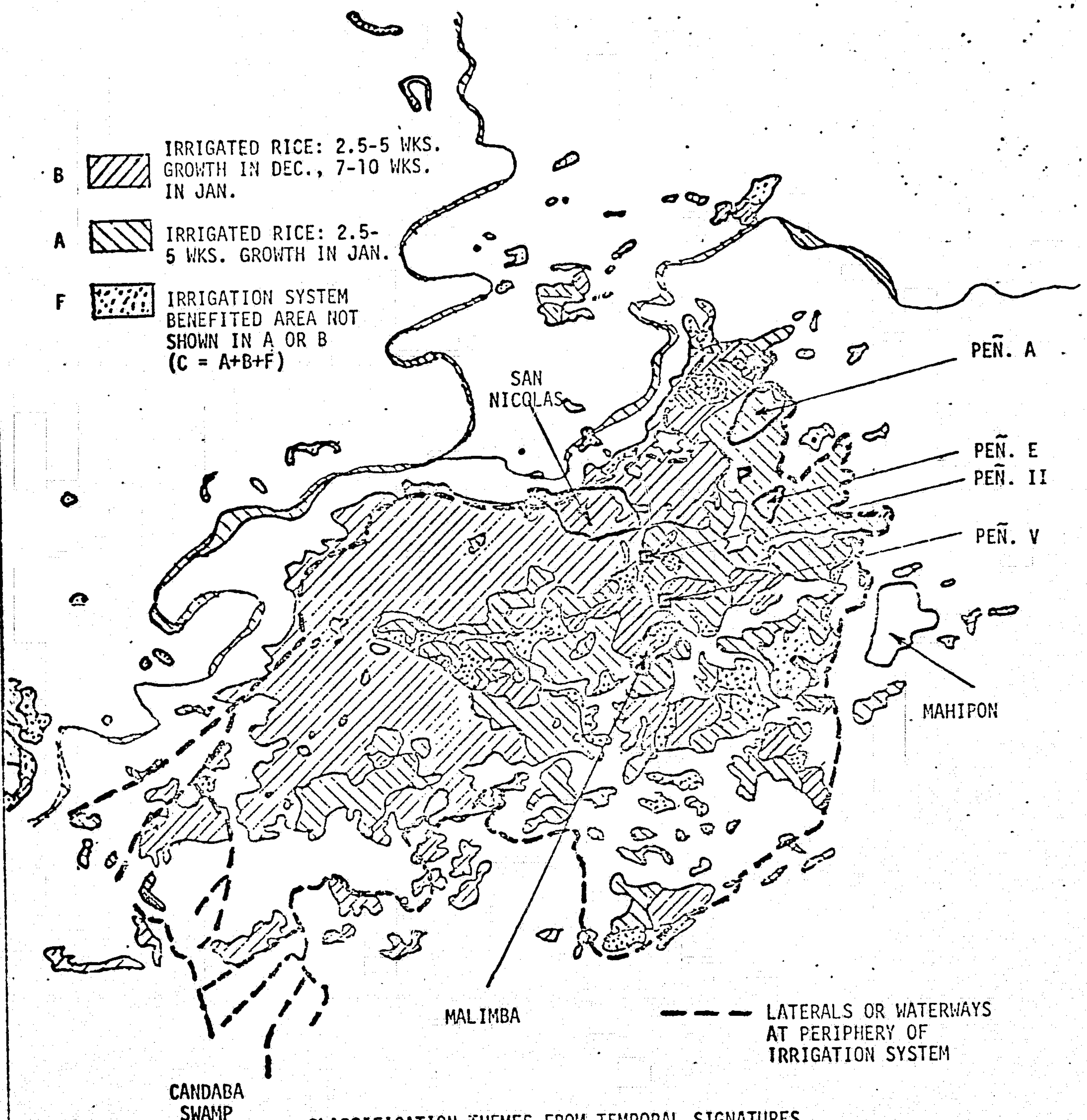
Figure 28. GAPAN REGION TEMPORAL CLASSIFICATION THEME C
SHOWING IRRIGATION SYSTEM BENEFITED AREA

temporal signature was modified slightly in an iterative procedure guided by Professor Miranda in accordance with his knowledge of ground truth in selected locations.

In Figure 29, the early- and late-planted rice themes, and the benefited area theme have been superposed and manually sketched to show the interrelationships of all three. The first two themes (A and B) do not overlap, and the benefited area theme (C) is essentially coincident with the sum of A and B except in a few areas where it includes neither A or B. Those few additional areas are shown as Theme "F" in the figure. The irrigation system laterals and other waterways at the periphery of the irrigation system have been extracted from ground truth maps and plotted on the figure for reference purposes.

In Figure 30 the spectral/temporal theme for mangoes is presented. Results essentially conform to ground truth in the region along the rivers north of the town of Gapan. Ground truth was not available for other portions of the scene, except that mangoes were not expected to be in the irrigation system area and the theme in fact did not indicate any in that area. The spectral/temporal signature for the mango theme was established by starting with the extracted spectral signature for mangoes for December. Then, knowing that mangoes maintain essentially the same appearance all through the year, the spectral/temporal signature was synthesized to show no change over four dates (October to June) for the spectral signature.

For spectral/temporal Theme E (crop between the rivers north of Gapan town), shown in Figure 31, the signature was established by training in the lower portion of that region using single-band four-date data. Ground truth for the specific crop type was not available, but from previously extracted spectral signature data the crop is obviously different from rice and its growth cycle differs from that for rice. For comparison purposes, the classification theme for the same crop is presented in Figure 32 using a four-band spectral signature extracted from training in June 1973 data for the same area.



CLASSIFICATION THEMES FROM TEMPORAL SIGNATURES

GAPAN REGION

Figure 29

AREA= 87796. PIXELS(33.49%) THEME TRACK 3 PRINTOUT DATE:01-JAN-72 PRINTOUT TIME:07:09:27

THEME D RESULTS FROM TRAINING USING 4-DATE SPECTRAL-TEMPORAL IMAGE DATA FOR 31 OCT 72, 23 DEC 72, 29 JAN 73 AND 21 JUNE 73. DECISION BOUNDARIES IN SPECTRAL SPACE WERE THEN MODIFIED TO PRODUCE THE PROPER ALARMED AREA IN THE SCENE IN THE JUDGMENT OF THE ANALYST.

GAPAN REGION TEMPORAL CLASSIFICATION THEME D
SHOWING MANGOES
Figure 30

THEME 5

AREA= 2560. PIXELS(0.97%) THEME TRACK 5 PRINTOUT DATE:01-JAN-72 PRINTOUT TIME:02:10:28

THEME E RESULTS FROM TRAINING (IN AREA BETWEEN THE RIVERS) USING 4-DATE SPECTRAL-TEMPORAL IMAGE DATA FOR 31 OCT 72, 23 DEC 72, 29 JAN 73 AND 21 JUN 73. DECISION BOUNDARIES IN SPECTRAL SPACE WERE THEN MODIFIED UNTIL THE ALARMED AREA BETWEEN THE RIVERS CORRELATED SATISFACTORILY WITH GROUND TRUTH.

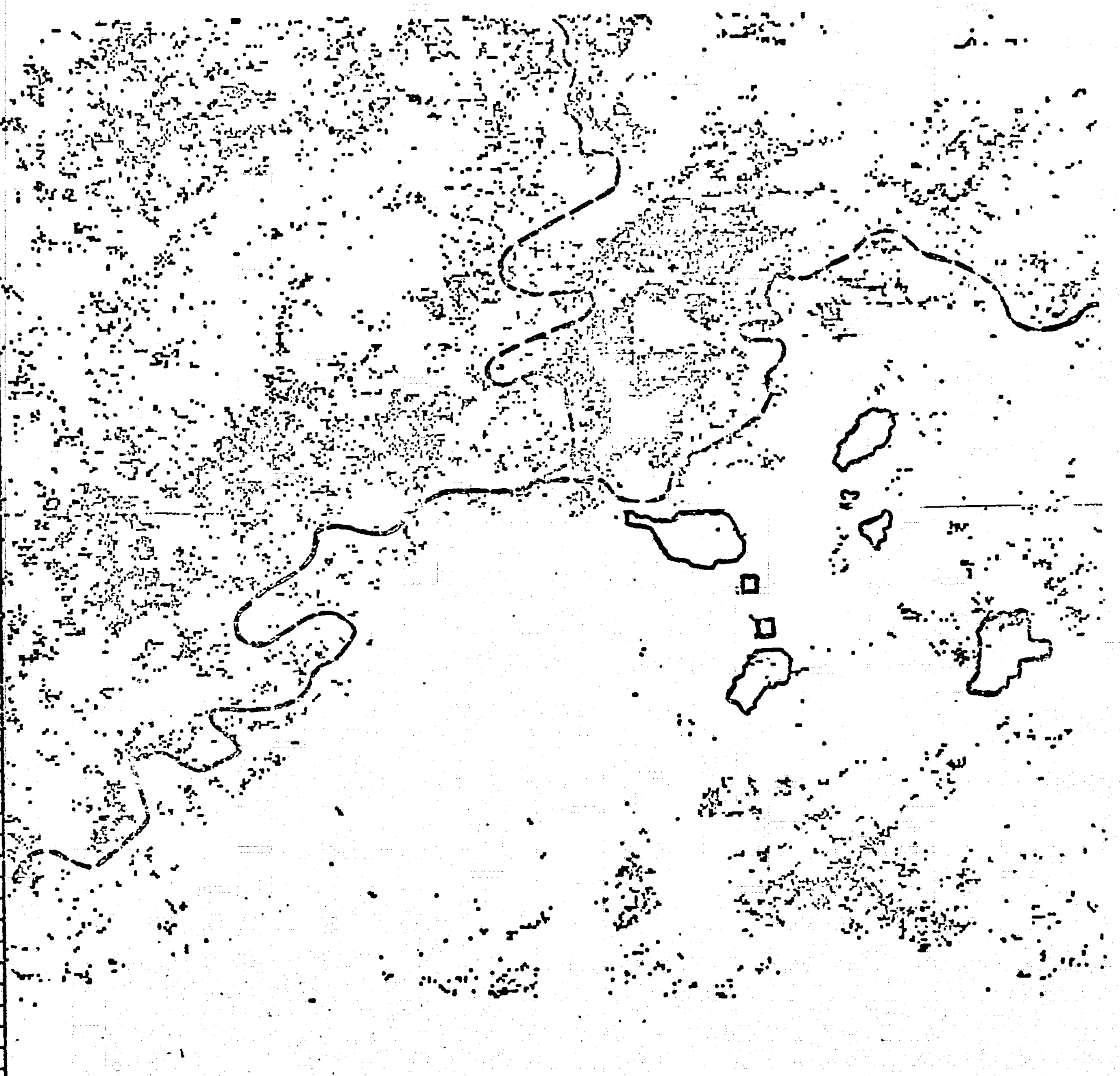


Figure 31. GAPAN REGION TEMPORAL CLASSIFICATION THEME E FOR THE AREA NORTH OF GAPAN TOWN AND SIMILAR AREAS

AREA= 25259, PIXELS 10.2101 THEME TRACK 1 PRINTOUT DATE 01-JAN-72 PRINTOUT TIME [illegible]

CLASSIFICATION THEME RESULTS FROM TRAINING (IN AREA BETWEEN THE RIVERS). USING 4-SPECTRAL BAND IMAGE DATA FOR 21 JUNE 73. DECISION BOUNDARIES IN SPECTRAL SPACE WERE THEN MODIFIED UNTIL THE ALARMED AREA BETWEEN THE RIVERS CORRELATED SATISFACTORILY WITH GROUND TRUTH.

Figure 32. GAPAN REGION SINGLE-DATE MULTISPECTRAL CLASSIFICATION FOR THE AREA NORTH OF GAPAN TOWN AND SIMILAR AREAS.

VIII ANALYSIS OF RESULTS

A. Incomplete Imagery During Growth Cycle

In the Gapan region, useful data from five Landsat 1 overflights became available. The dates of these five coverages were: 31 October, 18 November, 23 December 1972; 28 January, 21 June 1973. The first of these occurred near the end of the wet season harvest, but when some rice was still standing. Data for 18 November pertained to the period of site preparation, but the data were not used in the Image 100 analyses reported here (simply for reasons of economy of time and cost). The sets of data for 23 December and 28 January pertained to dry season (irrigated) rice in early and middle stages of growth, although for some late-planted sites the December data covered the end of site preparation. By the time of the 21 June overflight dry season rice had long since been harvested, and site preparation for the wet season was underway. For the Angat region, only the 23 December image data was fully usable due to cloud cover or frame coverage limitations. In this region, rice growth appeared to be about 3-4 weeks more advanced than near Gapan. That is, for December, rice appeared to exhibit 3-7 weeks growth. Thus, at best, our analyses pertain to one look at mid-harvest for a wet season crop, two looks at early and middle growth of rice during the dry season, and one look at site preparation for the next wet season. These samples have been of considerable value, but it must be recognized that we have been unable to study one complete growing cycle and, of course, unable to observe one full year of two (wet and dry season) crop cycles.

B. Applicability to Other Regions

Although we had timely ground truth for test sites in the Gapan region (IRRI and UPLB sites in the Peñaranda River Irrigation System), in the Angat River Irrigation System, and in the Santa Cruz River Irrigation System, only Landsat data for test sites in the first two regions were studies in this investigation--and most of that pertained to the Gapan region. Thus, it is not possible to state that results are generally applicable to other regions of the Philippines such as in northern Luzon or in Mindanao. It is felt, however, that the rice site cycle we have observed is likely to be similar in these other regions although the time phasing of the cycle may be different.

C. Two-Band VS. Four-Band Analysis

From the band to band correlation plots, and from a few actual tests of tentative scene classification using both two-band and four-band signature data, results seem to be about the same for the two-band and the four-band cases. (Other investigators have made similar observations for agricultural applications). Signatures from test sites were acquired in all four bands, but were applied to remaining areas of the scene sometimes using two bands and sometimes four. Multi-band Image 100 signature plots have been shown in this report as two-band signatures. Further tests would be necessary for a sound conclusion on the adequacy of two-band signatures, but we are inclined to feel that two bands are adequate for:

1) Site recognition and gross assessment of the site status (i.e., the site position in the overall site temporal cycle represented by the data).

2) Analyses where a combination of spectral and temporal signature data will be used.

For data analyses to establish detailed conditions at a site (e.g., yield prediction, differences due to variations in plant species or fertilization, etc.) it has not been determined whether more than two bands of data are necessary.

D. Geometric (Spatial) Positioning Accuracy Limitations

In the present program there were some difficulties in locating test site boundaries accurately and in entering these boundaries into the analysis system in the form of stored binary electronic site maps. These difficulties resulted in limitations to the overall analysis accuracy. First of all, the difficulty has been noted in identifying a particular location in the image data corresponding to a location in a map of the scene, such as a site map. This results from the very limited occurrence of easily recognizable scene features in the image data. Secondly, once the analyst locates particular points in the image data, he manually constructs and stores in the system the site boundaries and all the area within. This is done on a pixel by pixel basis. The result is the creation in the analysis system of a binary site map in which the accuracy of the stored site location, size, and shape is proportional to the time, care, and experience exercised by the analyst during this process. Limitations of the analysis machine time available during this portion of the investigation, in turn, limited the geometric accuracy of the stored site map. We estimate that any portion of the site boundaries may be improperly located by two to four LANDSAT pixels. For a future effort, however, it is estimated that with care the boundary location accuracy can be made to approach one or two pixels. Once this is accomplished, results are often useful for a considerable period of time since site boundaries are not likely to change very frequently.

E. Spectral Signature Variations with Spatial Displacements

Because of the heterogeneous, spatially fine-grain nature of all rice areas, and particularly of the test sites studied, all extracted signatures in this investigation actually are derived as a composite of field or crop conditions at the sites. This means, for example, we have not measured exact signatures for rice at three weeks growth and rice at five weeks growth. Rather, we have measured a signature for a composite set of fields where the growth may range from two and one-half to five weeks. This is probably adequate to establish the general signature cycle and a gross position within it. For purposes of detailed site status assessment, one should examine the signatures for groups of only a few contiguous pixels at a time--perhaps 9 or 4 or even fewer. Hopefully, conditions will be fairly uniform within such groups. In the current investigation, we were reluctant to perform signature extraction (training) for such small areas because of the possibility that slight errors in position location could cause the signatures to be associated with improper ground truth. In future programs, a more thorough use of location techniques can make it possible to work with the smaller, more homogeneous areas — particularly during the training (signature extraction phase). For the classification process in the future, the operation probably should be performed on a pixel by pixel basis, although it may be possible to use a coarser spatial resolution, if desired, by employing analysis of the spectral signature distribution in N-space for

the coarser spatial cell.

F. 64- and 128-level Radiometric Resolution

Signatures were extracted during the present investigation using a radiometric resolution of 64 levels in each spectral band (for Image 100 analyses of digital data). This was considered to be entirely adequate for purposes of site recognition and gross site status. A finer grain radiometric resolution (i.e., 128 levels) likely would not improve discrimination between certain scene features and rice since signatures for these features fell within the observed rice temporal signature cycle. Such discrimination is possible, however, by using spectral-temporal signatures, or by first establishing that rice is or is not grown at a particular location and then exploiting the spectral signature. For detailed assessment of rice status at a particular location, we expect that the use of 128-level radiometric data, when available, will be beneficial and perhaps essential. Obviously, such fine or finer resolution levels are beyond the capability of a manual visual system.

G. Spectral Signature Extraction Using 1-D and N-D Training

As noted previously, spectral signature extraction via Image 100 in this investigation involved 1-D training.* This was considered adequate for purposes of site recognition and for establishing the gross site temporal signature cycle. For detailed rice status classification for large areas, the N-D signature* or the maximum likelihood classification algorithm are likely to produce better accuracy. Such a sophisticated approach will be most appropriate, however, only when training areas can be very accurately located in the scene data.

H. Temporal Signature Cycles in Multiple Bands

The plots of site mean intensity level vs. time in each spectral band are of some value for purposes of site recognition and gross site status assessment. It has been shown, however, that the rice temporal signature cycle exhibits significant variations in two spectral bands. It has also been shown that a spectral/temporal signature (as previously described) has considerable power. These latter approaches appear to be the preferable routes to follow.

I. Two-Band Spectral/Temporal Signature

The derived two-band temporal signature cycle for irrigation system rice, Figure 25, must, of course, be considered only an estimate until additional data samples are available pertaining to many points in the cycle and derived from several site locations and satellite passes. Nevertheless, the Figure derived by this project is believed to be a reasonably accurate and useful approximation since:

a) Four general locations in the cycle have been identified based on data from six or more test sites in two regions (Gapan, Angat).

b) Extracted signatures for four other land features appear to properly bracket and calibrate the rice signature path. These are tidal

*See Appendix I

flats, lush swamp vegetation, rain fed areas in Angat during the beginning of the dry season, and much of the Gapan region (except for swamp, mangoes, and crop area north of Gapan town) at the end of the dry season.

The general practice of draining the rice fields a few weeks before harvest also suggests an increasing band 5 (red) radiation and a stable or decreasing band 6 (IR) radiation as harvest approaches. The estimated signature cycle is consistent with this. No attempt has yet been made, however, to pinpoint the path of the two-band mean signature or the variance associated with it.

J. Spectral/Temporal Signature Applications and Discriminations

Spectral/temporal signatures employed in this investigation (specifically, in the IMAGE 100 analyses of digital data) were single-band two-date signatures or single-band four-date signatures, with the single band being MSS Band 6. These choices were made at the start of the machine analysis period on the assumption that they represented a reasonable and useful approach, but were not necessarily optimum. In retrospect, the use of two-band, two-date or perhaps two-band three-or four-date signatures would have been more effective.

Spectral/temporal signatures for themes A and B* (late-planted and early-planted dry season rice in the Gapan region) were established from analysis of previously extracted spectral signatures for such rice. The same is true for the signature for Theme C (Irrigation System Benefited Area), except that the signature limits in 2-space were iteratively adjusted while the resulting classification signal in the training area was observed. Professor Miranda guided this interactive procedure, drawing on his familiarity with ground truth conditions. The early- and late-planting themes show rice conditions in the test site areas which are consistent with ground truth, as should be expected. But they also indicate conditions elsewhere in the irrigation system which conform to ground truth to the best of Miranda's judgement. Further, the sum of the early- and late-planting themes adds up, with a few small omissions, to the benefited area theme. From inspection of the temporal signatures in Figure 24 or 25, these omissions can be seen to be due to the difference between temporal signature C and the composite of temporal signatures A and B.

The spectral/temporal theme for the benefited area conforms well to the boundaries corresponding to the irrigation system peripheral laterals except in some areas in the southern (lower) portion of the system. Professor Miranda advises that gaps in this region are areas where it is known that the existing irrigation system is not effective. In general, that kind of information is most useful to irrigation system managers and planners.

At the upper right in classification Themes A and C (Figures 26 and 28), cloud shadows are found to be improperly included in the themes (which pertain partially or entirely to dark areas such as recently planted and flooded rice fields). This erroneous classification can be avoided or minimized in future analyses. It is quite likely, for example, that two-band, two-date signatures will circumvent this difficulty.

*See Figure 24 and 25

The discrimination power of spectral/temporal signatures versus spectral signatures is apparent from an examination of both types of signatures for several kinds of features in the scene. That power is illustrated in the classification Theme D (for mangoes) (Figure 30) in which virtually none of the Gapan rice area shows a mango classification (although rice field and mango spectral signatures are similar at certain times during the rice cycle). A second striking illustration of the power is found in the comparison of the classification themes of Figures 31 and 32. In both cases there was training in the crop area between the rivers north of Gapan town, followed by classification of similar areas in the overall scene. The signatures used differed in the two cases, however. One was a four-date, single-band signature (Theme E) and the other a single-date four-band signature. The classification themes for both signature types enhance essentially the same crop region between the rivers, but the theme based on the spectral/temporal signature enhances much less of the remainder of the scene than does the spectral signature theme. This indicates that the crop in the region between the rivers is truly different from much of the remainder of the scene, although that would not be evident using single date spectral signatures alone. Further, from comparison of the temporal pattern of the spectral signature for this crop and for rice, one can conclude the crop is not rice.

A final observation should be made concerning spectral/temporal signatures as used in this investigation. The signature for Theme A (see Figure 24 or 25) is used to seek out and classify rice which has about one-month of growth in January (and which, therefore, was transplanted in December). If one wishes to seek out and classify rice which is one-month old in December, an analogous but temporally shifted spectral/temporal signature can be used. This is simple to implement in the machine analysis, and assumes only that available registered image data exists for November as well as for December and January.

K. Comments on Geometric Fidelity

A few comments are in order relative to the geometric fidelity of the machine analysis system printout of classification and other themes. It has been noted previously that, for the theme printouts in this investigation, the horizontal and vertical (northerly and easterly) scales are different. This is due to the fact that the LANDSAT digital data involves over-sampling in the cross-track direction. Suitable computer software for interpolation to new picture element values for the overall data frame, such that uniform scale is achieved for the horizontal and vertical directions, is entirely feasible. Such software was not available, however, at the time of this investigation.

A second correction required to produce theme printouts with proper geometric fidelity is de-skewing of the digital data. This compensates for the effect of Earth rotation during acquisition of the data. De-skewing of the data was performed in this investigation, but it was subsequently recognized that the amount of correction used was improperly chosen. For future analyses, proper correction is now known and available.

Thus, with the different horizontal and vertical scales, and an improper level of skew correction, it was difficult in the present investigation to geometrically correlate points in the image data with corresponding points in a map -- particularly, when there are only a few recognizable reference points in a scene. This will be much less of a problem in future analyses.

IX. CONCLUSIONS

A. Accomplishment of Initial Objectives

Initial objectives of the investigation included determing whether lowland rice sites can be detected from LANDSAT data and whether the status of these sites, including rice growth status, can be assessed from the same data. The conclusion, which must be tentative, is that:

1) Lowland rice sites can be readily detected if data from more than one satellite overflight is used.

2) Site status (preparation, idle, etc.) and rice growth status (stage in growth cycle) can be determined from the satellite data and expressed in number of hectares.

3) Investigation was not sufficiently extensive to determine if detailed rice growth status can be determined from the satellite data (i.e., questions concerning assessment of rice vigor, biomass, plant variety, etc., remain to be answered). Preliminary values can be detected. Analysis correlated with ground truth looks promising.

Conclusions 1) and 2) must be tentative to the extent that only two lowland rice regions (Gapan, Angat) in Luzon were analyzed, although we believe similar results would have been achievable if other rice regions had been analyzed. The conclusion must be tentative also for the reason that a limited number of satellite overflight data samples were available to be analyzed: Mid-harvest for the 1972 wet season; site preparation, early growth and mid-growth for the 1972-73 dry season; and site preparation for the 1973 wet season. No satellite data were available at rice later growth, maturity, and harvest at the end of the 1972-73 dry season, so that it was not possible to achieve analyses covering one complete growth cycle.

An objective which became apparent later in the investigation was to determine the feasibility of extracting from LANDSAT data the boundaries of benefit of an irrigation system (i.e., the area beneficially being served by an irrigation system). This was suggested by Professor Miranda of the University of the Philippines at Los Baños, who observed that current information concerning the benefited area would be useful to irrigation system managers. From such information, a return on investment can be estimated for new or improved irrigation systems, and a decision can be made more intelligently concerning possible additional investments. The conclusion is that it is possible to establish the area benefited by an irrigation system from LANDSAT data from two or more overlfights at appropriate dates. Here also, the conclusion must be tentative for reasons previously identified concerning limited overflight data and limited regions analyzed in the present investigation.

B. Digital, Machine-Aided Visual, and Manual Visual Data Analyses

For recognition of rice sites and gross site status, LANDSAT color composites for multiple dates would enable reasonably accurate results to be achieved employing either manual or machine-aided analyses. The process would be tedious even with machine aids, particularly where multi-date imagery for the same locations must be examined. For detailed rice growth status assessment, LANDSAT digital data should be used. If this is to be accomplished in an operational system, it would make sense to perform both the site recog-

nition and also the gross site status assessment using the digital data. Because of the complexity of the scene in the Philippine environment, the use of a high-speed man-machine interactive analysis system is virtually mandatory to achieve efficiency and timely results in an operational analysis system which examines large rice-growing areas.

C. Small Test Site Areas

Where it is necessary to pin-point locations in a scene accurately (i.e., within one or two pixels), digital data, properly corrected geometrically, is almost always necessary coupled with careful triangulation from the limited recognizable reference locations in the scene. It is estimated that this process is feasible, although it was not fully implemented in the present investigation. The need for accurate position location arises particularly in the signature extraction process for small training areas which, of necessity, must be small in order to contain homogeneous rice or site conditions.

D. LANDSAT Adequate for Rice Recognition

LANDSAT spatial resolution is estimated to be adequate, but barely so, for the purpose of detailed assessment of rice or site status, particularly when the assessment pertains to an accurately located small area. This is due to the spatially fine-grain, heterogenous nature of most rice areas. For rice site recognition and gross site status assessment, the LANDSAT spatial resolution is considered to be satisfactory.

E. Correlation Between ERTS/LANDSAT Data and Ground Truth

Correlation between ground truth and information extracted from LANDSAT data was good, within the following framework:

1) For analysis of five rice test sites in the Gapan region, two rice areas in the Angat region, several non-rice land or vegetation conditions in Gapan and Angat regions (mangoes, rain-fed areas, swamp, tidal flats, etc.), and for data from four LANDSAT overflights (October, December, January, June).

2) For determination of the area deriving benefit from the Gapan region irrigation system using spectral/temporal signatures.

3) Excluding small test sites (Peñaranda C, II, V) where results are highly dependent on achieving position location accuracies of one or two pixels.

4) Excluding detailed assessments of site and rice status, which were not pursued to the fullest extent in the present investigation.

5) Using LANDSAT digital data and a man-machine interactive analysis system.

F. Two-Band Spectral Digital Data, Preliminary

Use of two spectral bands of digital data (MSS 5 and MSS 6 or 7) appears to be adequate for site recognition and gross site status assessment. It is not yet known whether more than two bands of data are necessary for detailed assessment of site and rice growth status.

G. Two-Band Spectral Digital Data, Additional Overflights

A two-band spectral/temporal signature cycle for irrigation system rice has been synthesized from analyses of digital data and correlations with ground truth. The general nature of this signature cycle is considered to be valid, although it should be quantified further with additional data samples--particularly for points in the rice growth cycle where LANDSAT data to date has not been available. The signature cycle should be validated also for rice regions other than the two studied in the present program.

H. Spectral/Temporal Signature: One-Band/Multiple-Date; Two-Band/Two-Date

Spectral/temporal signatures were found to be more powerful than spectral signatures alone and virtually essential for most analyses of rice growth and rice sites in the Philippine environment (i.e., in an environment where there is vegetation at most locations during nearly all months of the year, and in which non-rice vegetation near rice sites has signatures similar to rice at some point in the rice signature cycle). Two-band, two-date signatures are estimated to be adequate for most purposes, although good results were achieved using one-band and two- or four-date signatures.

I. 64-Level Radiometric Resolution

For the analyses of LANDSAT digital data for site recognition and gross site or rice growth assessment, a radiometric resolution of 64 levels in each band is adequate. For detailed rice or site status assessment, 128 levels may be necessary, but this has not yet been established. For the former functions, as noted previously, spectral/temporal signatures are used. But once the spectral/temporal signatures indicate that rice is grown at a particular location, then spectral signatures alone are likely to be used for detailed status assessment.

J. Area Determinations

Using LANDSAT digital data, areas in hectares can be extracted accurately from the data for various classification categories (e.g., benefited area, area in preparation phase, area of rice having reached growth maturity, etc.) under the following conditions:

1) A dependable digital analysis system is used to count all pixels falling within a given classification category on a pixel by pixel basis.

2) The classification of any category is performed accurately.

3) Suitable accounting is taken (i.e., the proper conversion factor from pixel count to hectares) in measuring the areas represented by small isolated groups of pixels of less than 10 pixels each. The conversion factor here will be different from that for larger sized groups of pixels due to oversampling of LANDSAT data in the cross-track direction.

4) The "border-pixel" problem (i.e., pixels straddling two classification categories) is taken into account--particularly for small or narrow individual areas in a classification theme. This implies

a procedure (technology) exists for handling the border pixels, and an appropriate set of signatures for all classification categories.

The area measurement accuracy problem is not unique to the investigation undertaken here, and was not specifically addressed in this investigation.

K. Concerning an Operational System

After additional analyses (similar to those already performed) of LANDSAT data covering other lowland rice regions and including data samples through compelte wet and dry season growing cycles, it should be feasible to implement an operational analysis system to provide the following information concerning lowland rice in the Philippines (or elesewhere in Southeast Asia):

1) Boundaries (including location and size) of irrigation system benefited areas.

2) Locations and hectares for areas where rice growth is underway.

3) The approximate stage of rice growth in the complete growth cycle for each location.

4) The rice site status at each location (preparation, transplanting, rice growth, harvest).

X. RECOMMENDED FUTURE EFFORT

An orderly program building on the present investigation, to fully achieve and exploit the overall program objectives, should be as follows:

RESEARCH AND ANALYSIS PROGRAM

← TASK 1 →

← TASK 2 →

← TASK 3 →

← INITIAL OPERATIONAL SYSTEM →

← OPERATIONAL SYSTEM, PHASE II →

← OPERATIONAL SYSTEM, PHASE III →

Research and Analysis Task 1 provides the basis for proceeding with the Initial Operational System. Tasks 2 and 3 of the Research and Analysis Program are similarly related to Operational System Phases II and III.

The information output of the Initial Operational System for lowland rice, described previously under Conclusion K, pertains to recognition and status assessment for rice sites, and to gross assessment of rice growth. Preceding the implementation of this system is Research and Analysis Task 1, which should include:

1) Analysis of LANDSAT data samples covering complete wet and dry season growing cycles and pertaining to several geographically diverse lowland rice regions which are representative for the Philippines.

2) Further refinement (maintaining simplicity is important) of signatures and classification techniques, and some additional testing of these.

Task 2 of the Research and Analysis Program pursues further the matter of extracting detailed lowland rice growth status from LANDSAT data. This shall include determining biomass versus time, yield prediction, assessing plant vigor or stress, exploring the possibilities for determining the effects of fertilization and water treatments and for recognizing differences in rice plant varieties. Results of this task would be exploited in the implementation of the Operational System, Phase II.

Research and Analysis Task 3 is concerned with extending the techniques and procedures associated with lowland rice to other crops. These should include first such large contiguous major area crops as sugar cane and coconut. Then, attention should be given to crops which are grown in numerous small, noncontiguous minor areas such as upland rice and root crops. Possibly pineapple and rubber should be considered also. Again, the results

of this task are exploited in the Operational System, Phase III. The Operational System thus is an evolving system which grows in its capability to extract and provide more and more useful information from the same sets of LANDSAT data.

APPENDIX I

DESCRIPTION OF SOME APPLICABLE IMAGE-100 OPERATIONS

A. Read-in, and the Analysis Frame

Scene data read-in refers to filling the Image 100 video disk from a digital tape with scene picture elements (pixels) each of which may have associated with it four channels of 8-bit (256 levels) data. An array of up to 512 x 512 pixels are stored on the disk for analysis and display. The fact that all pixel data in this array may be accessed at high speed is key to the real-time man-machine interactive capability of Image 100.

B. Geometric and Radiometric Scale Factors

Data associated with one pixel of the source data may be placed in two or more adjacent pixel cells on the video disk. This sets the geometric scale factor. The signal level information (radiometric data) may be placed on the disk with a multiplying scale factor relative to the source radiometric data. For example, a signal level of 52 in a data source having a maximum level of 256, may be stored on the video disk as a level of 104 on a 256-level scale (i.e., radiometric scale factor of 2:1).

C. Radiometric Resolution for Analysis

Although the pixel radiometric data is or can be stored on the video disk with a granularity of 256 levels from minimum possible to maximum possible level in each channel, it may be analyzed with a radiometric granularity of 128, 64, 32, etc., levels, as selected by the operator.

D. 1-D Training

For this operation the analyst first defines a training area in the scene by appropriately locating an electronic cursor in the TV display of the scene, and by setting the size and shape of that cursor. The system then examines the radiometric data in four channels (4-space) for all pixels, in the training area and determines the maximum and minimum actual signal levels in the four channels. These eight values may be envisioned as the eight plane surfaces of a parallelepiped in 4-space.

Note: More sophisticated training areas may be employed, but these are not discussed here.

E. 1-D Alarm and Classification

When the four-channel radiometric data for all pixels in the analysis frame are systematically searched, every pixel whose four-channel radiometric location in 4-space (i.e., signature) falls within the four-dimensional parallelepiped established from 1-D training then will be "alarmed." A distinctive binary alarm signal is available which can be displayed to show the location of alarmed pixels. The alarm signal may be counted to obtain a measure of the alarmed area in terms of number of pixels. Pixels anywhere in the analysis frame which have been alarmed as indicated here are considered to be classified as falling in the same category as the training area. If the training area pertains.

to a particular type of vegetation, then alarmed pixels are considered to be classified as that same type of vegetation. This is a 1-D classification.

F. Theme and Theme Track

The binary alarm signal comprises, for the complete analysis frame, a binary map or theme. Such a theme may be stored on the video disk along with the four-channel radiometric data for each pixel. The theme stored on a theme track may be displayed or accessed rapdily for other purposes.

G. 1-D Threshold Adjustment

1-D thresholds are the eight values corresponding to the eight parallelpiped surfaces in 4-space resulting from 1-D training. These values or surfaces may be considered to be thresholds in the classification process since pixels whose signatures fall within the parallelepiped are alarmed, and pixels who signatures fall outside are not alarmed. As part of the Image 100 1-D training procedure (a real-time, interactive, and iterative procedure), the analyst may alter the thresholds which were obtained in the initial 1-D training process. He does this after making interpretation judgements while viewing the alarmed areas in the scene display, and while studying 1-D historgrams displayed for each channel of radiometric data pertaining to the training area.

H. N-D Training and Classification

If, for example, the radiometric resolution for analysis has been set at 256 levels in each of four channels, 4-space will consist of 256 x 256 x 256 x 256 elemental cells each of which is a parallelepiped. The signature vector for any pixel in the scene must fall in one of the elemental cells of 4-space. Obviously, for an analysis frame of 512 x 512 pixels, there will be a large number of 4-space cells which are not occupied. In the N-D training operation, the specific elemental cells in 4-space which are occupied by the training area pixels are identified. Then, in the N-D classification step, pixels in the total scene are alarmed if their signatures fall in any one of the identified elemental 4-space cells. This is a more sophisticated but also more powerful training and classification procedure than the 1-D method. A parameter in the N-D training operation is the population threshold for the 4-space elemental cells. For example, only those 4-space cells may be identified which have n or more pixels associated with each of them. Here, n = 1, 2, 3, etc., and the value is set by the analyst.

I. Window Mode

In any scene being analyzed, a selected area within the analysis frame may be reconstructed so that each original pixel will appear as 2 x 2, 3 x 3, . . . or 9 x 9 pixels. This provides an electronic magnification of a portion of the scene to assist the analyst in the interpretation of the display of the video scene and themes.

J. Level Slicing

This refers to setting thresholds (analogous to 1-D thresholds described in G) in one selected channel of the four channels. Two methods are

available. In one method the system will automatically set thresholds to provide eight equal slices between the minimum and maximum actual signal levels in that channel. In the second method the analyst may set the individual thresholds at any desired level so that non-uniform or arbitrarily located slices may be specified when desired. In either method the resulting slices produce alarms (themes) during the classification process.

K. Clustering

In this operation the analyst first uses the cursor to define a training area in the scene. He also specifies his interest in the N most dense clusters in 4-space for the training area. (Loosely, a cluster may be considered as a concentration in 4-space of occupied elemental 4-space cells). Through an iterative process, Image 100 identifies the clusters (i.e., identifies the 4-space elemental cells in each cluster). Then, each pixel is alarmed in the analysis scene if its signature falls into one of the 4-space elemental cells for a given cluster. The system causes a theme to be entered onto a theme track in the classification process associated with each cluster. If six clusters were identified, six classification themes are produced. This overall procedure is essentially an unsupervised training and classification operation.